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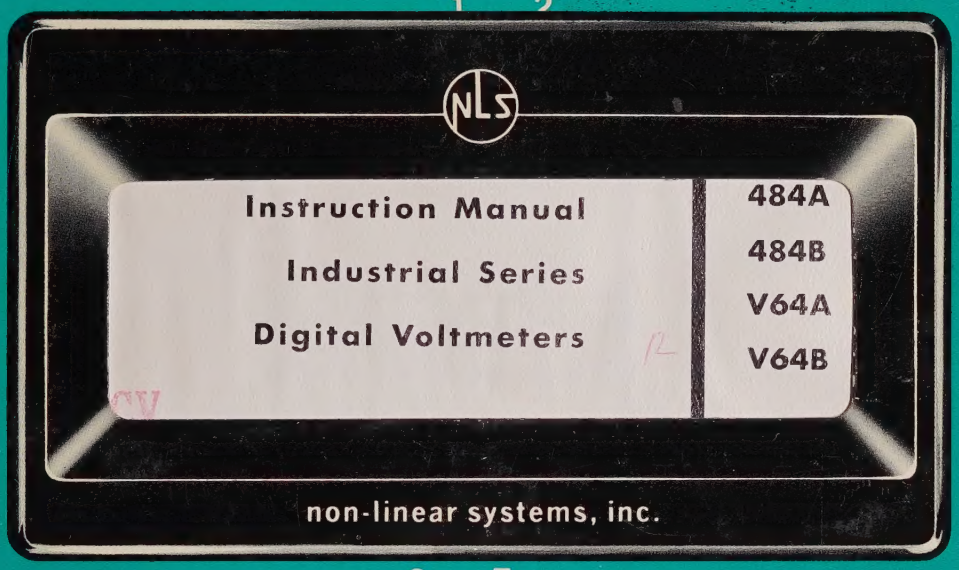

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DEL MAR, CALIFORNIA

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Instruction Manual

Industrial Series

Digital Voltmeters

484A

484B

V64A

V64B

METROLOGY

This manual is for instrument Serial No._____

non linear systems, inc.

DEL MAR, CALIFORNIA

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CONTENTS

Page		Section	
1	Application . . . Features . . . General description	INTRODUCTION	I
3	Accuracy . . . Ranges . . . Controls . . . Dimensions	SPECIFICATIONS	II
5	Setting up the instrument . . . Grounding . . . Connecting to power source . . . Using the controls	INSTALLATION AND OPERATION	III
9	The potentiometer principle . . . Simplified schematics . . . Digital Logic . . . Reference Supply . . . Printer Operation	THEORY OF OPERATION	IV
21	Basic Settings . . . Hum, standardization, and range adjustments . . . pulse waveforms	CALIBRATION	V
27	Access . . . Parts Identification . . . Test Equipment . . . Zener Supply . . . Stepping switch plug-in assemblies . . . Troubleshooting chart	MAINTENANCE	VI
39	Listing by unit assembly . . . Spares Requirements	PARTS LIST	VII
47	Warranty . . . Shipping notice . . . Short form catalog . . . List of sales and service representatives . . . Ratio conversion . . . Schematics	APPENDIX	VIII

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ILLUSTRATIONS

Number		Page
2-1	Outline View of Model 484A Digital Voltmeter.	3
3-1	View of Printed Circuit directly below Power Switch as Seen from Component Side of Amplifier Board.	5
3-2	Digital Voltmeter, Rear View.	6
3-3	Digital Voltmeter, Front-panel View.	7
3-4	V64B Range Input Attenuator.	8
4-1	Basic Potentiometer Circuit.	9
4-2	Potentiometer with Calibration Rheostat.	10
4-3	Simplified Schematic, Single-Range Digital Voltmeter for Measuring Absolute DC Voltages.	11
4-4	Simplified Circuit Diagram; 4-Digit, Multirange, Manually Standardized Digital Voltmeter for Measuring Absolute DC Voltages.	12
4-5	Chopper Output Waveform and Resulting Pulses at Error Amplifier Output and to Decade Switches for Various Relations Between Unknown Input and Feedback Voltages.	13
4-6	Pulse Switching Circuits.	16
5-1	Top View of Digital Voltmeter with Cover Removed.	21
5-2	Amplifier-Power Supply (Unit 1) with Cover Removed.	22
5-3	Typical Pulse Waveforms.	23
6-1	Bottom View of Digital Voltmeter with Cover Removed.	27
6-2	Stepping Switch Board Assemblies, Top View with Switches Removed.	28
6-3	Stepping Switch Assembled, with lifting Handles in Raised Position.	29
6-4	Identification of Principal Stepping-Switch Parts.	31
6-5	Stepping Switch Wiper Tip Travel Limits.	33
6-6	Readout, Showing Bulbs Correctly Installed.	34

INTRODUCTION

Section One

NLS Industrial Series Digital Voltmeters are rugged, simple, and accurate. Since the four instruments described in this manual are really four versions of the same basic assembly, only one instrument is described. In this manual the Model 484A designation is used to represent all instruments within the Industrial Series. Users of the 484B, V64A, and V64B versions will find the content wholly applicable except as indicated on this page. The Parts List, Section Seven, is keyed to the 484A. However, the component circuit references are the same for all instruments in the Series, although the 484B, V64A, and V64B use fewer parts. Schematic drawings of each instrument are at the end of the manual.

The following three subsections describe the difference between the basic 484A and the other instruments of the Series:

1. Model 484B (Part Number 11381)

The Model 484B is operated, calibrated, and maintained as described in this manual. Unlike the 484A, the 484B does not have the capability of working with a remote printer. Because of this, the front-panel POWER switch provides only OFF, STANDBY, and ON settings. Schematic drawing 11375 at the end of the manual is wholly applicable if all printer functions and components are disregarded.

2. Model V64A (Part Number 11376)

The V64A is a simplified version of the 484A; the Specifications listed on Page 4 apply in all areas which are common to both instruments. However, the V64A, as a simplified instrument, has a narrower range of capabilities as here noted:

V64A	484A
Range and polarity are selected by front-panel controls.	Range and polarity are automatically selected and indicated.
No printer connection.	Printer connection.
No internal calibrator.	Built-in standard cell.
Provides digital voltmeter functions only.	Provides both digital voltmeter and digital ratiometer functions.

Since the V64A is not equipped with a built-in standard cell, it is calibrated with customer-supplied standard cells connected to the input. A series bank of standard cells which provides between 9,000 and 9.999 volts should be used. The accuracy specification of the instrument is dependent upon the accuracy of the cells used. The calibration controls in the V64A are the same as described for the Model 484A in the Calibration Section of the manual.

3. Model V64B (Part Number 11379)

The V64B is the lowest-priced digital voltmeter in the Industrial Series. In all respects this instrument is similar to the previously described Model V64A *except* that it has only a single voltage range and will read up to 10 (9.999) volts. The calibration procedure for this instrument is the same as for the V64A except, of course, that there are no upper voltage ranges to be calibrated.

If it is desired to measure voltages above the basic range of the V64B, a small, separately cased input attenuator, complete with filter, is available. This input accessory is described on page 8 of the manual.

Please contact your regional NLS sales and service branch for additional information. Also, queries may be directed to the Engineering Department, NLS, Del Mar, California.

SPECIFICATIONS

Section Two

Type of Input Signal Measured:
Absolute DC voltage and ratio.

Number of Digits Displayed:
Four.

Reference Voltage:
Internal, temperature compensated, zener diode type DC power supply with zener diode mounted in an oven, or external for ratio.

Standardization:
Manual.

Voltage Range, DC Volts:
±9.999/99.99/999.9.

Ratio: 1:1 - 10:1 - 100:1, Ser. No. 200 and lower. Ratio is 1:1 for Ser. Nos. above 200.

Range Changing:
Automatic.

Polarity Indication:
Automatic.

Accuracy:
± 1 digit. Deviations which can occur with time include:

LINEARITY ± 1 digit.
SCALE MULTIPLIER ±0.01% of reading.
STANDARDIZATION ±0.01% of reading.
Calibration pots permit bringing instrument into agreement with user's voltage standards.

Resolution:
1 digit.

Average Balancing Time:
1.0 second.

Input Impedance:
10 megohms. For ratio measurements 1000 megohms on Ser. No's. 201 and up.

Printer Operation:
Hewlett Packard 561B or NLS 155 may be directly driven. Printer Modes are auto-continuous and manual.

Weight:
Net 32 lbs.; shipping 35 lbs.

NOTE:

These specifications fully apply to the Model 484A and, except for differences noted in the Introduction, to the 484B, V64A, and V64B as well.

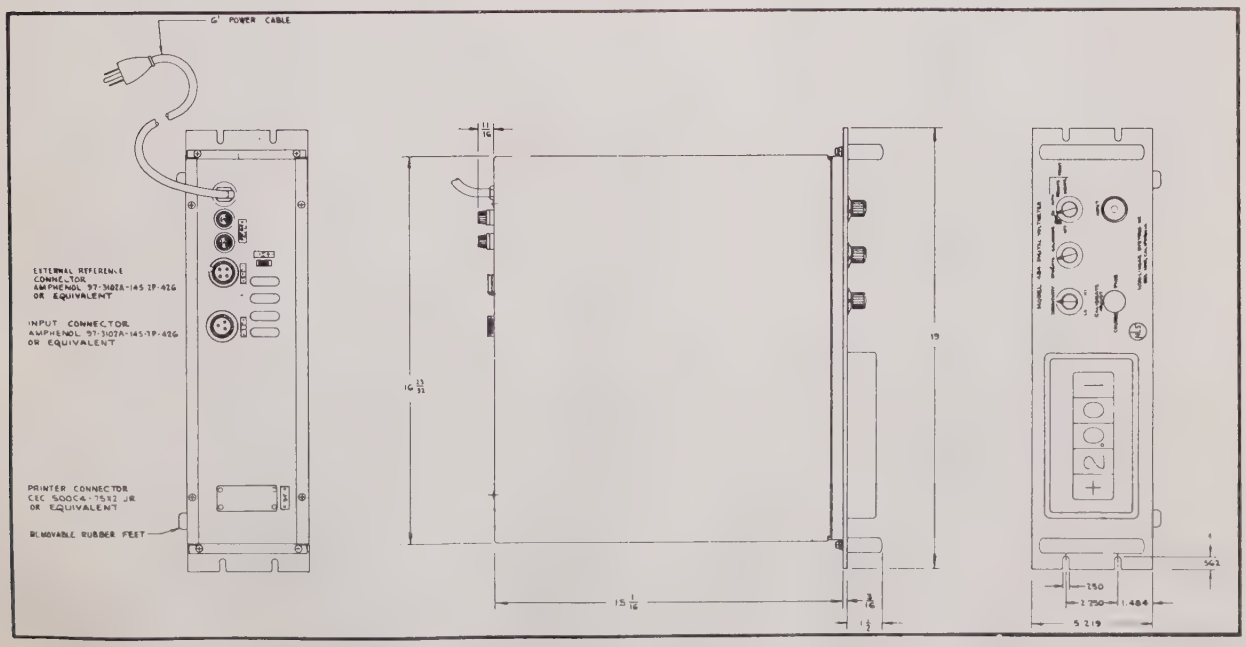

6' POWER CABLE
EXTERNAL REFERENCE CONNECTOR AMPHENOL 97-3102A-14S-2P-426 OR EQUIVALENT
INPUT CONNECTOR AMPHENOL 97-3107A-14S-7P-426 OR EQUIVALENT
PRINTER CONNECTOR CEC 5006A-25S2 JR OR EQUIVALENT
REMOVABLE RUBBER FEET

Figure 2-1. Outline View of Model 484 A Digital Voltmeter.

I Primary Power

The Model 484A Digital Voltmeter operates from 105 to 125 or 210 to 250 volt 60-cycle power sources. Primary power requirements for this instrument are satisfied by most nominal 115 or 220 volt alternating current power lines. However, digital measuring equipment, as well as many other types of electronic equipment will operate improperly when connected to a power line with abnormal characteristics, such as low or high voltage, large transient changes, or large amounts of amplitude modulation. Also, high-voltage "spikes" generated by certain types of welding equipment, thyratron-controlled machine tools, and the like, can cause the digital voltmeter to give erratic indications. The outputs of many types of line voltage regulators are very rich in third harmonic content, thereby causing unstable operation and apparent loss of resolution in the digital instrument. Operation from such voltage regulators is, therefore, not recommended.

If the Model 484A is to be operated from a 230-volt alternating current source, certain modifications are made. The instrument is normally supplied ready for 115-volt AC operation and the following four steps provide necessary information for converting the instrument to 230-volt use. Refer to Figure 3-1 when making the change from 115 to 230 volt operation.

1. Interchange the grey and the black primary leads going to spots 1 and 2.
2. Remove the jumper from between spots 3 and 4.
3. Move the white wire from spot 5 to spot 4.
4. The instrument is now wired for 230 volt operation.

II Grounding the Instrument

Connect the red clip on the test lead to the signal "high" side, and the black clip to the signal ground. Connect the third lead (bare clip) to shield ground or chassis ground. Input connectors are available at the front and back of the instrument. See Figure 3-2 for identification of rear connectors and fuses.

CAUTION

The signal ground terminal (black clip) is connected to the chassis through a 1-ampere fuse for printed circuit protection. The chassis, in turn, may be connected to earth ground through the third wire of the power input cord. If a signal above ground is connected to the black clip, and if the chassis is connected to the power ground of the instrument being tested with the digital voltmeter, then a short circuit will occur and the fuse will blow.

To permit the instrument to make above-ground measurements, a 1 mfd. capacitor shunted by a 1 megohm resistor has been provided between signal ground and chassis ground. These parts are shorted by the 1 amp. fuse discussed in the preceding caution note. When this fuse is removed, above-ground measurements may be readily made.

III Shielding and Grounding

Adequate shielding in grounding the instrument is necessary if high accuracy, high resolution, and

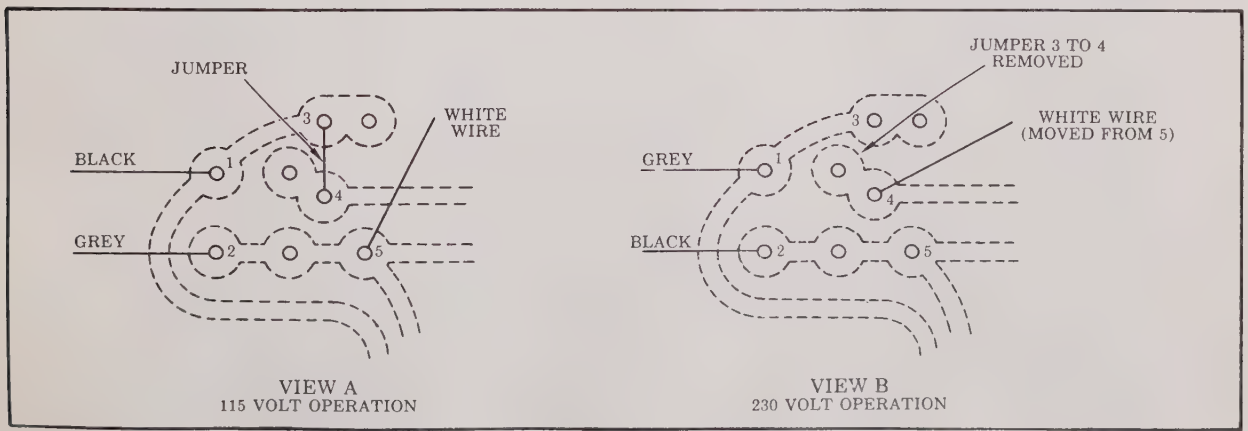


Figure 3-1. View of Printed Circuit directly below Power Switch as Seen from Component Side of Amplifier Board.

Section III
INSTALLATION AND OPERATION

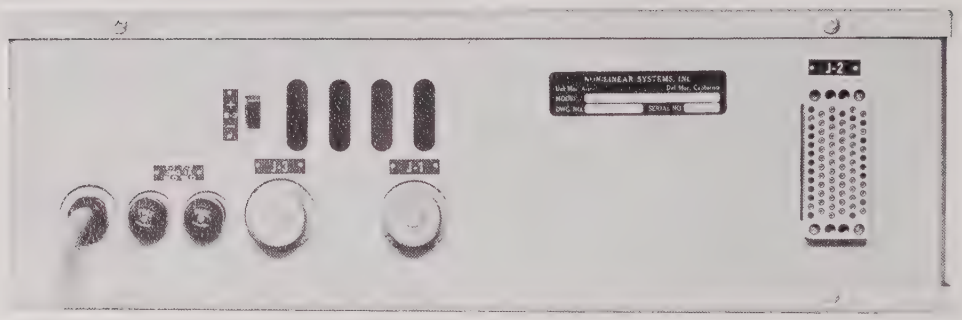


Figure 3-2. Digital Voltmeter, Rear View.

high input impedance are to be maintained. As with standard laboratory type instruments, certain conditions must be met to assure the proper operation of the 484A digital voltmeter.

1. Shield both input leads. The lead connected to the digital instrument's signal ground can act as an antenna and pick up stray noise, as can the input signal "high" side lead. The noise pick-up problem increases, of course, when the impedance of the source being measured is high.
2. Ground the instrument chassis. In most locations the AC power line receptacle ground or water pipe ground will be adequate. In rare instances a better earth ground will be required. If trouble is encountered, a measure of the potential differences between various grounds is often quite revealing. Difficulties with electronic equipment in general are often removed by the use of good earth grounds.
3. Make certain that the black clip is connected to the ground side of the signal regardless of polarity. When measuring the voltage between two points isolated from ground, connect the black clip to the point having the lowest impedance to ground. As true with most electronic measuring instruments energized from a power line rather than from isolated batteries, errors may result when measuring sources whose "low" side is not at ground potential.
4. Observe the usual grounding precautions taken with most electronic instruments to avoid bias and ripple effects produced by ground loops.
5. Excessive electrical noise pick-up can cause one or a combination of the following: (a) Unstable readout; (b) A loss of resolution (i.e., the digital voltmeter will not respond to small changes in input signal); (c) A bias or offset error in the readings.
6. Where excessive electrical noise is present at the digital instrument input terminals, external filtering of the signal may prove helpful. Note that the series resistance of an external filter can cause errors because of the voltage drop. While this may occur with any type of measuring instrument, the high resolution of digital instruments makes the possible error more apparent.

Note that unstable readout of digital instruments can be caused by actual variation in input signal amplitude; such variations are not ordinarily detected with other instruments of lower resolution. When this happens, a stable reading may be obtained by simply backing off the SENSITIVITY control to the point where the readings will be made stable.

IV Cooling

Do not subject the 484A to operating temperatures in excess of 110°F. The standard cells must be maintained below 122° F, ambient.

V Leveling

The instrument may be operated in any position convenient for viewing.

Section III
INSTALLATION AND OPERATION

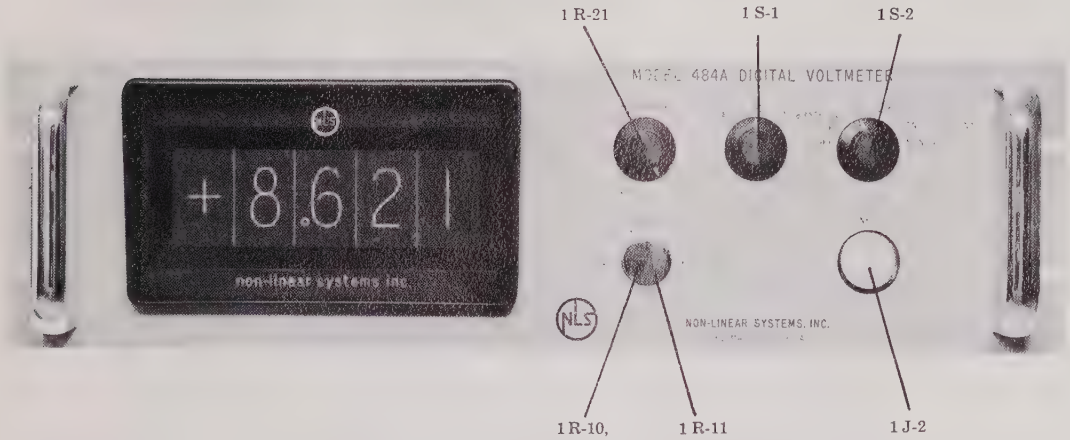


Figure 3-3. Digital Voltmeter, Front-panel View.

VI Front Panel Controls

The front panel has three controls, as shown in Figure 3-3.

POWER SWITCH: The POWER switch has six positions. OFF—At OFF the instrument is completely de-energized. STANDBY – The STANDBY position permits keeping the instrument warmed up with the stepping switches turned off. This reduces needless stepping-switch operation and also permits locking the reading at any particular value. After turning the POWER switch ON, a delay of 15 to 30 seconds is provided by a thermal timer to keep the thyratron plate power off until the filaments have become heated.

ON – The instrument is in operating mode.

PRINT – The printer controls are also a part of this switch.

Three modes of operation are provided:

AUTO – In this mode the printer records once each time the meter reaches a balance.

CONTINUOUS – This position provides for remote control of the print command.

MANUAL – This position provides for print command to be started at any time by the operator. In each case the meter will balance before printer operation occurs.

SENSITIVITY: The SENSITIVITY control is continuously variable with maximum sensitivity occurring in the fully clockwise position. The Model 484A digital voltmeter sensitivity and resolution are 1 part in 10,000 of the full scale value. If the input signal is rapidly changing more than this amount, the instrument will not give a fixed reading, but will continually search for a reading. To enable proper operation with a fluctuating input, the SENSITIVITY control allows the gain of the instrument to be reduced. When measuring changing voltages, slowly back off the SENSITIVITY control until the meter settles out on a fixed reading. This reading will be as accurate as the signal is stable. When through with such readings always return the SENSITIVITY control to the full clockwise position for proper operation with stable DC voltages.

OPERATE-CALIBRATE CONTROL: This control is to be held in the spring-loaded CALIBRATE position when the instrument requires standardization. For details see Section V, Calibration.

RATIO-DC-CALIBRATE CONTROL: In the RATIO position the instrument is used with an external + or — 10-volt reference source which the user can connect through connector 1J-3 on the rear panel of the instrument. In the DC setting, the internal reference supply is connected to the instrument. When held in the spring-loaded CALIBRATE position, the instrument may be standardized by following instructions in Section V, Calibration.

VII Accessory Range Attenuator

An accessory range attenuator, (shown in Figure 3-4,) is available for the Industrial Series instruments. Primarily intended to extend the basic range of the Model V64B, this accessory is also useful for applications requiring remote range switching, or for applications in which it is desirable to isolate the range-switching function from the instrument itself. This useful accessory is equipped with an input filter to reduce the effects of stray voltages at the input. See schematic 15126 at the end of the manual.

Figure 3-4. V64B Input Range Attenuator.

THEORY OF OPERATION

Section Four

Introduction

The Model 484A Digital Voltmeter, in common with other Non-Linear Systems' digital voltmeters, are best described as digital, self-balancing potentiometers, which, in measuring the unknown input, set up an equal or proportional voltage. The term "potentiometer" in this larger sense, applies to a system including a variable voltage divider, a reference voltage source, and a null detector, all of which are used to measure input voltages by establishing an internal voltage equal to the input.

I The Potentiometer Principle

Figure 4-1 shows schematically a basic potentiometer circuit. If an unknown voltage is supplied, and the variable voltage divider is adjusted until the voltage E_0 is equal in magnitude to the unknown voltage, then zero current will flow through the galvanometer. During this balance condition no current is drawn from the input. The unknown voltage can be computed from the formula:

$$\text{Unknown Voltage} = \frac{R_1}{R_1 + R_2} \times \text{Ref. Voltage E}$$

If the polarity of the input voltage is reversed, then the reference voltage must also be reversed to obtain balance. The galvanometer pointer will now travel in an opposite direction as the magnitude of the unknown voltage increases. It is this change in error signal sense which necessitates not only reversing the reference voltage, but also the error amplifier output lines in the digital voltmeter when input signal polarity is reversed.

A. MEASURING ABSOLUTE VOLTAGES WITH THE POTENTIOMETER: To measure the absolute value of an unknown voltage, the reference voltage must be known. Instead of accurately measuring the reference voltage directly, it can be adjusted to the proper value if an accurately known voltage is available for use as a calibration reference. With this method, a standard cell of known voltage is connected in place of the unknown voltage (See Figure 4-2), the variable voltage divider dial set to this known voltage, and the voltage across the variable voltage divider adjusted by means of rheostat R_c to obtain balance. The potentiometer is now calibrated or standardized and is ready for use as an absolute voltage measuring device. This is analogous to the method employed in the digital voltmeter.

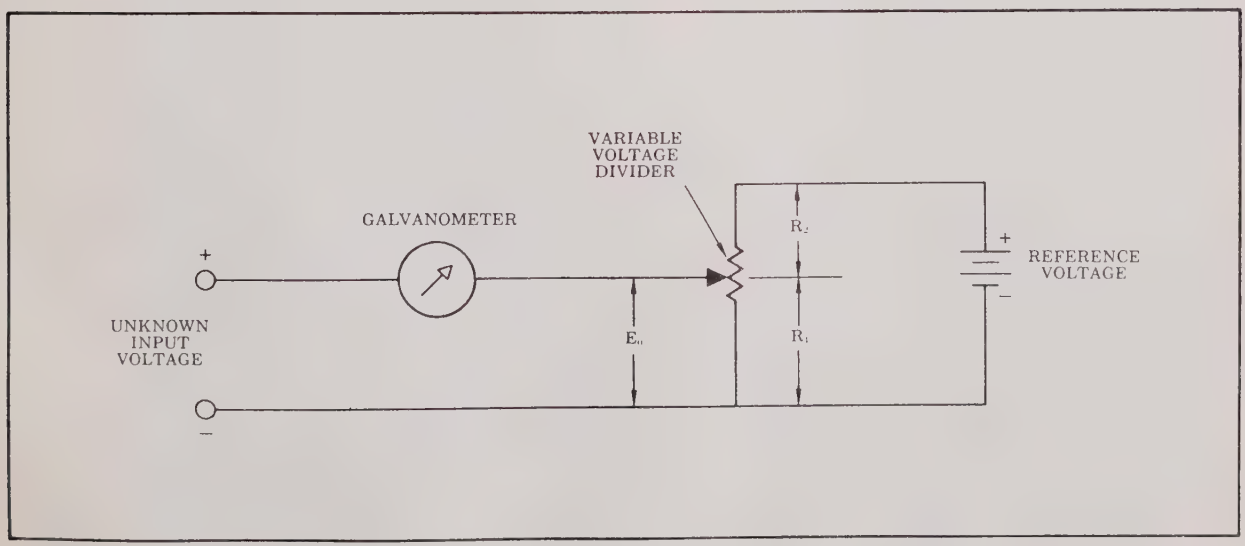


Figure 4-1 Basic Potentiometer Circuit.

Section IV
THEORY OF OPERATION

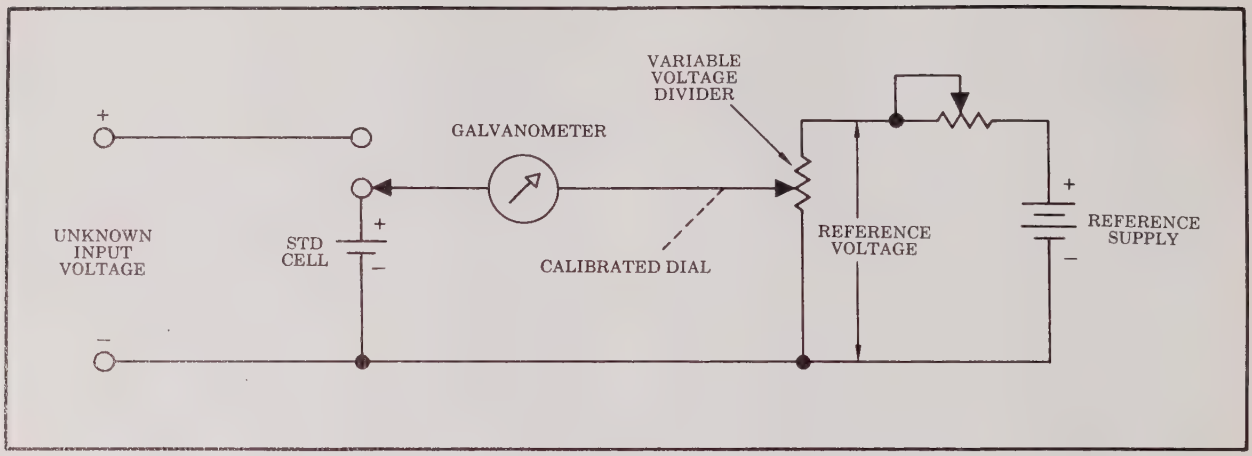


Figure 4-2. Potentiometer with Calibration Rheostat.

B. DIGITAL VOLTMETER PRINCIPLE: As earlier said, NLS stepping-switch type digital voltmeters are essentially self-balancing digital potentiometers. Simplified schematics are shown in Figures 4-3 and 4-4. A stepping-switch-operated variable voltage divider, composed of wire-wound resistors, divides the reference voltage into a large number of precisely equal parts in the decimal number system. These particular stepping switches are called decade switches. An error amplifier compares this divided voltage, called the feedback voltage, with the input signal, and commands stepping switch motion in a logical sequence until the two voltages are equal within the limits of the instrument's resolution. This stops stepping switch motion, and the instrument is said to be at balance. Input to the error amplifier is provided through an electromechanical chopper. Automatic range and polarity changing are provided by a combination range and polarity switch (See Figure 4-4).

There is a basic relationship between the number of steps (assuming equal steps) in the stepping-switch-operated variable divider, the reference voltage amplitude, and error amplifier "gain" (error amplifier gain defined as the smallest difference between the unknown input voltage and feedback voltage which will produce a pulse output from the error amplifier):

$$\text{Amplifier gain} = \frac{\text{Reference voltage amplitude}}{\text{Number of steps in variable voltage divider}}$$

Using, as an example, a four digit instrument with a 10-volt reference:

$$\text{Amplifier gain} = \frac{10}{10{,}000} = 0.001 \text{ volt.}$$

If the reference voltage is increased or decreased, the error amplifier gain is proportionately decreased or increased if the instrument is to be returned to normal operation. If the error amplifier gain or reference voltage is too high, the instrument may oscillate; if either is too low, the resolution of the instrument will tend to decrease. However, if amplifier gain is lower than nominal, the instrument will still increase its numerical display in steps of one digit in the right-hand window of the digital readout as the input signal is slowly *increased*. But if amplifier gain is lower than nominal, the digital instrument will decrease its numerical display by "X" digits (where "X" is two times the quantity obtained by dividing actual error amplifier gain by nominal error amplifier gain) if the input signal is slowly decreased.

For example, if amplifier gain is supposed to be 0.001 volt but is actually 0.002 volt, then the displayed reading would decrease by 4 digits each time it changes (e.g. 4.959, 4.955, 4.951, etc.) if the input voltage is being slowly decreased. This is because the error amplifier is kept operating over only 0.001 volt of its null region as the input voltage is slowly increased, but the error amplifier must go from one end of its null region, through zero, and then to the opposite end of its null region each time the numerical display decreases by one digit in the right-hand window.

Section IV
THEORY OF OPERATION

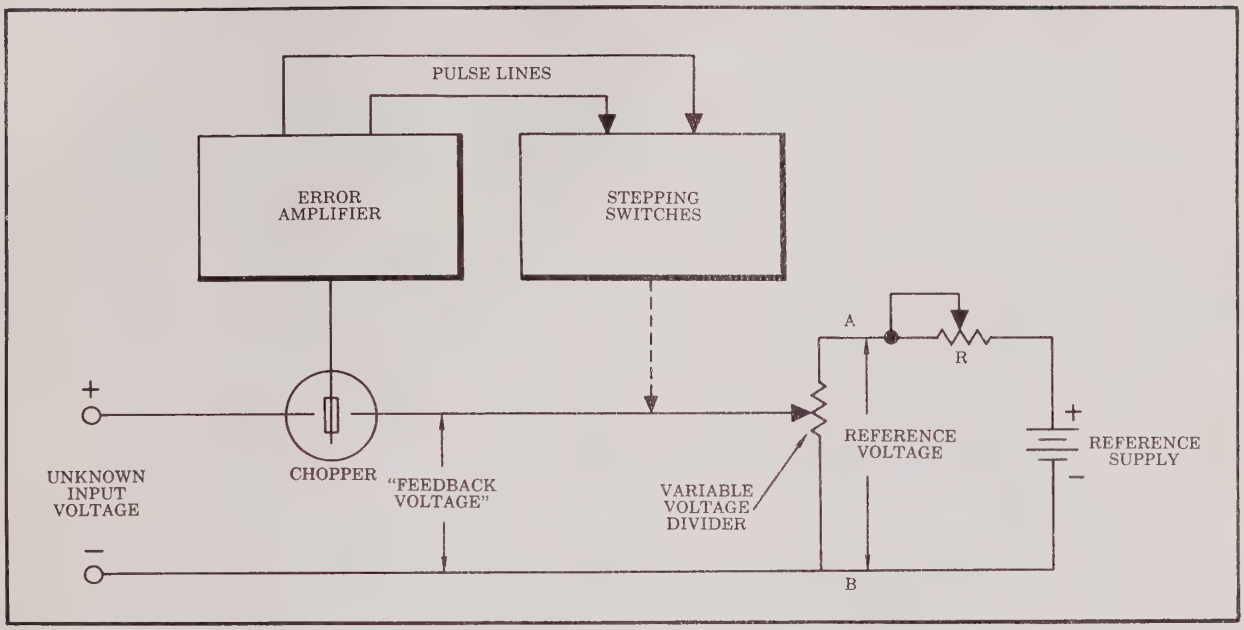


Figure 4-3. Simplified Schematic, Single-Range Digital Voltmeter for Measuring Absolute DC Voltages.

The SENSITIVITY control on the panel enables the operator to reduce the gain from its nominal value so that varying signal voltages can be measured. This control is normally kept in the fully clockwise position.

C. REFERENCE VOLTAGE: The DC voltage impressed across the stepping-switch-operated Kelvin-Varley voltage divider is called the reference voltage. If absolute DC voltages are to be measured accurately, a precision DC reference voltage must be used. Unsaturated cadmium standard cells provide an extremely accurate and stable DC voltage, but are incapable of supplying the amount of current required to energize the Kelvin-Varley voltage divider. Therefore, reference voltage power supplies which use standard cells as primary references have been developed.

Matched zener diodes of equal and opposite temperature coefficients perform the final regulation of the DC reference voltage. These diodes are located within a crystal oven which holds the temperature to within $\pm$ ½° C. As a result, the zener voltage is held stable to better than 1 part in 10,000 over considerable periods of time with wide ambient temperature variations. DC power is supplied to the zener diodes by a transformer-rectifier-gas reference tube-type supply. This supply is highly stable, but exhibits a long term drift which is manually compensated by operating the front panel CALIBRATE switch, and adjusting the front-panel screwdriver operated CALIBRATE controls until the displayed reading is 1019. This procedure standardizes the instrument by connecting an internal unsaturated cadmium cell to the error amplifier input; the CALIBRATE adjustments permit changing the reference voltage supply output to the proper value using the precise emf of the standard cell as a standard reference voltage. Standardization needs to be made only once every several hours during use.

D. RATIO REFERENCE VOLTAGE: When the instrument operates in the RATIO mode, an external reference voltage is applied by the user through connector 1J-3 of Unit 1. Pin A is +, pin B is —, pin C is signal ground. This voltage may be in a range $\pm$20% of the nominal 10-volt reference requirement without noticeable loss of resolution in the instrument.

E. ERROR AMPLIFIER: The error amplifier acts as the null detector, or balance detector, in the digital instrument. It compares the feedback voltage and unknown input voltage appearing at the

Section IV
THEORY OF OPERATION

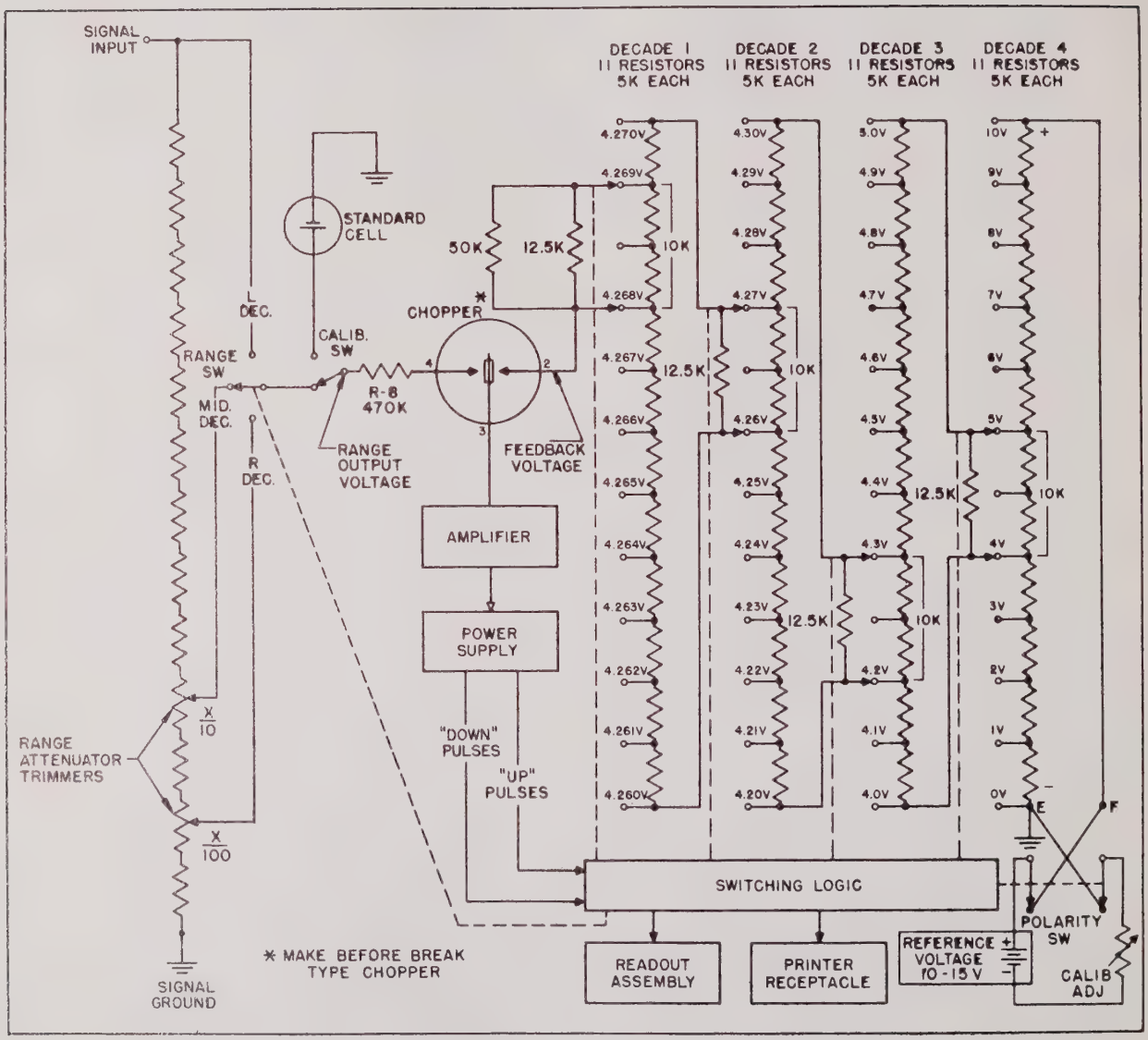
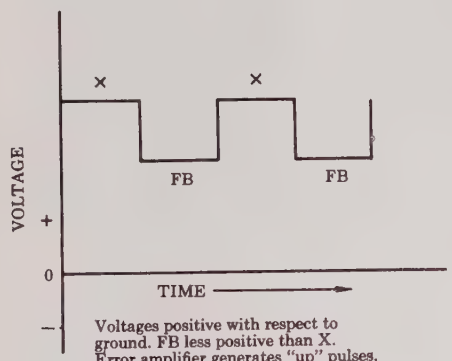
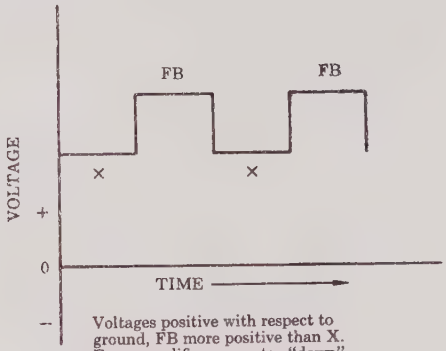


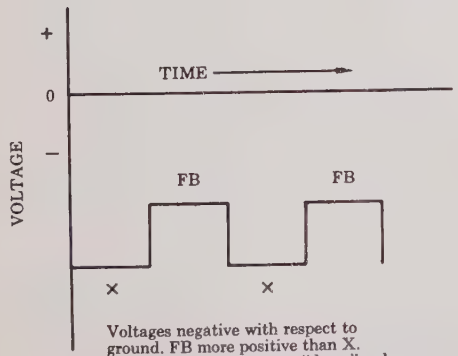
Figure 4-4. Simplified Circuit Diagram; 4-Digit, Multirange, Manually Standardized Digital Voltmeter for Measuring Absolute DC Voltages.



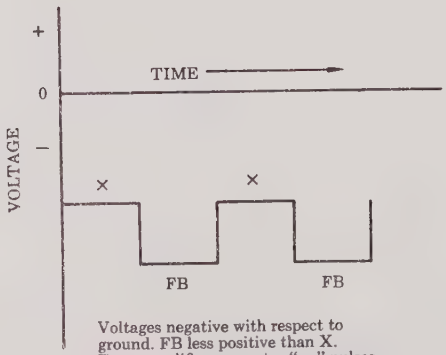
Voltages positive with respect to ground. FB less positive than X. Error amplifier generates "up" pulses, decade switches get "up" pulses.



Voltages positive with respect to ground, FB more positive than X. Error amplifier generates "down" pulses, decade switches get "down" pulses.



Voltages negative with respect to ground. FB more positive than X. Error amplifier generates "down" pulses, decade switches get "up" pulses because polarity switch reverses pulse lines.



Voltages negative with respect to ground. FB less positive than X. Error amplifier generates "up" pulses, decade switches get "down" pulses because polarity switch reverses pulse lines.

X = UNKNOWN INPUT VOLTAGE
FB = FEEDBACK VOLTAGE

Figure 4-5. Chopper Output Waveform and Resulting Pulses at Error Amplifier Output and to Decade Switches for Various Relations Between Unknown Input and Feedback Voltage.

range unit output, and issues pulses to drive the stepping switches to adjust the feedback voltage and cause the instrument to reach an electrical balance. The error amplifier is phase sensitive, and issues these pulses on its "up" or "down" pulse output line, depending upon the amplitude and polarity relationships between the unknown input voltage and feedback voltage (See Figure 4-5).

F. DIGITAL LOGIC OR SWITCHING LOGIC: Digital logic, or switching logic, means the pre-determined sequence of switching operations which cause the digital instrument to attain an electrical balance. This switching sequence is determined by way of the logic levels on the stepping switches as they are connected in any one switch and between the switches. These logic levels are electrically isolated from all other switch levels. The inputs to the switching system logic levels are the "up" pulse and "down" pulse lines from the error amplifier. Each pulse applied to a stepping-switch coil causes the switch to move one step. Since the stepping switches can mechanically rotate in only one direction, "up" pulses cause the switches to rotate in the same direction as "down" pulses; the manner in which these "up" pulses and "down" pulses are routed from one stepping switch coil to another causes the switches to reach a position where the instrument is electrically balanced. A combination of "up" and "down" pulses is usually required to attain an electrical balance.

G. RANGE AND POLARITY CHANGING: Automatic range and polarity changing is achieved with a single stepping switch. One level of this switch operates the range attenuator, two levels reverse the reference voltage, and two additional levels reverse the "up" and "down" pulse lines. An additional level is used to avoid an "0" in the left-hand window when in the 1000-volt or 100-volt range. The most sensitive range is always selected because of this interlock.

H. DIGITAL READOUT: The digital readout numerals and other symbols are engraved on plastic plates which are edge-lighted by incandescent lamps energized through an additional level of each stepping switch. These levels are electrically isolated from all other levels.

II Detailed Circuit Description

A. STEPPING SWITCH ASSEMBLY

Incorporated in the stepping switch assembly are range, polarity, and decade (feedback voltage generation) stepping switches, and the feedback voltage generating precision resistors (Kelvin-Varley circuit). Each stepping switch is mounted on its own plug-in decade assembly. Any stepping switch assembly may be readily removed for maintenance or replacement. All external connections to a stepping switch are made with AMP taper tabs. This permits any switch to be removed without the use of a soldering iron.

1. Stepping Switches: Each switch consists of a bank of stationary contacts arranged in a semicircle along with a bank of mating rotary wiper contacts which are rotated by a driving mechanism. The switches travel in one direction. When the driving mechanism electromagnet is energized, an armature is pulled toward the coil against the force of a helical spring. This motion causes a pawl to move back one step along a ratchet mounted on the rotary contact bank shaft; this action "cocks" the switch but does not advance the contacts. When the electromagnet is de-energized, the helical spring restores the armature to its original position, pushing the pawl assembly which is coupled to it. The pawl, in turn, rotates the ratchet and, therefore, advances the rotary contacts by one step.

Off-normal and interrupter contacts are eliminated from stepping switches in NLS instruments because of the unique digital switching logic used. Multi-level stepping switches are necessary since one set of electrically isolated contacts is used for operating the digital readout; several are used for the digital logic circuits; and several others are used for potentiometric circuits, including polarity reversal, range selection, and feedback voltage generation.

2. Development of Feedback Voltage: Feedback voltage is developed by a stepping-switch-operated Kelvin-Varley voltage divider which divides the reference voltage into a large number of equal increments as shown in Figure 4-4.

Each decade is operated by an individual stepping switch. The Decade 1 switch is associated with the least significant figure on the readout (right-hand window). The other three decades are numbered 2, 3, and 4 from right to left (from the least significant to the most significant figure). Each decade is capable of dividing the voltage applied across it into ten equal parts as shown in Figure 4-4. In other words, the reference voltage can be divided into 10x10x10x10 or 10,000 equal steps. Remember that the nominal error amplifier gain should allow an "up" or "down" pulse to be

generated if the input and feedback voltages differ by an amount equal to one step of the Kelvin-Varley divider with the sensitivity control in the fully clockwise position.

One advantage of the Kelvin-Varley type divider is that only 43 resistors are needed to divide the reference voltage into 10,000 equal parts. Furthermore, the absolute accuracy of the resistors does not need to be ±0.01% to achieve a linearity of ±0.01% of full scale. The decade resistors associated with the most significant figure in the left-hand readout window are the most critical. These are matched at the factory for best accuracy, but the probability of achieving 0.01% linearity when a 0.05% resistor is used as a replacement for one which has failed is extremely favorable. Resistors used in the second most significant figure decade are only one-tenth as critical as those in the most significant figure decade, and so on, until in the least significant decade inaccuracies up to 10% can be tolerated without appreciable effect upon instrument linearity. However, highly accurate, stable, aged wire-wound resistors are used in all decades to reduce somewhat the relatively stringent accuracy requirements of the two most significant decades and to produce an instrument of over-all high quality. Another advantage of the Kelvin-Varley circuit is that the effect of stepping switch contact resistance upon linearity decreases as we progress from the most significant figure decade to positions of less significance. Incidentally, the Kelvin-Varley voltage divider is, in a large sense, self-checking. This aspect is described in Section VI, Maintenance.

B. DIGITAL LOGIC

Many aspects of the digital voltmeter may be understood without an appreciation of digital logic. Yet, if digital logic is understood, the steps required in getting the instrument to attain a balance when the input voltage is changed to a new value can be readily worked out with the aid of the digital voltmeter's circuit diagram or with a pulse circuit schematic. Two points should be remembered when working out digital voltmeter operations.

First of all, the error amplifier generates pulses on its "up" pulse line whenever the feedback voltage is less positive than the unknown input voltage, and generates pulses on its "down" pulse line for the opposite condition. If the unknown input voltage is negative with respect to ground, these pulses are interchanged by the polarity switch prior to entering the rest of the digital logic circuitry. If the input voltage is positive, these pulses will pass directly through the polarity switch to the digital logic circuitry without being interchanged.

Secondly, the stepping switches operate mechanically in one direction; therefore, both "up" and "down" pulses always move the wipers in the same direction. The manner in which "up" and "down" pulses the routed through the polarity, range, and numerical decade stepping switches permits attaining balance and establishes the sequence of operations in doing so. In attaining balance, the digital voltmeter's switching operations proceed in a logical sequence toward balance in a manner which requires both "up" and "down" pulses.

1. Pulse Switching Circuits: Five stepping switches are used, one for range and polarity, and four for the four-decade Kelvin-Varley voltage divider. Each switch has several levels for routing the "up" and "down" pulses to the proper stepping switch coil as shown in Figure 4-6. Decades 1, 2, and 3 are interchangeable; each one uses three levels. Decade 4 uses four levels, and the range-polarity switch uses three levels. The stepping sequence for the switches is:

Range-Polarity	Decade 4	Decades 1, 2, and 3
+ 1000 V	1	0
+ 100 V	0	1
+ 10 V	2	2
cross over	3	3
− 1000 V	4	4
− 100 V	5	5
− 10 V	6	6
cross over	7	7
	8	8
	9	9
	99	99

The 99 and 9 positions are different only in the logic switching levels.

2. Up Pulse Routing: If the input signal is positive, "up" pulses leaving the range-polarity switch are connected to the Decade 1 (right-hand digit) stepping-switch wiper and, through the switch contacts, will step the wiper once per pulse. If balance is not attained within that decade, and the decade is driven up to 99, the "up" pulses are transferred to

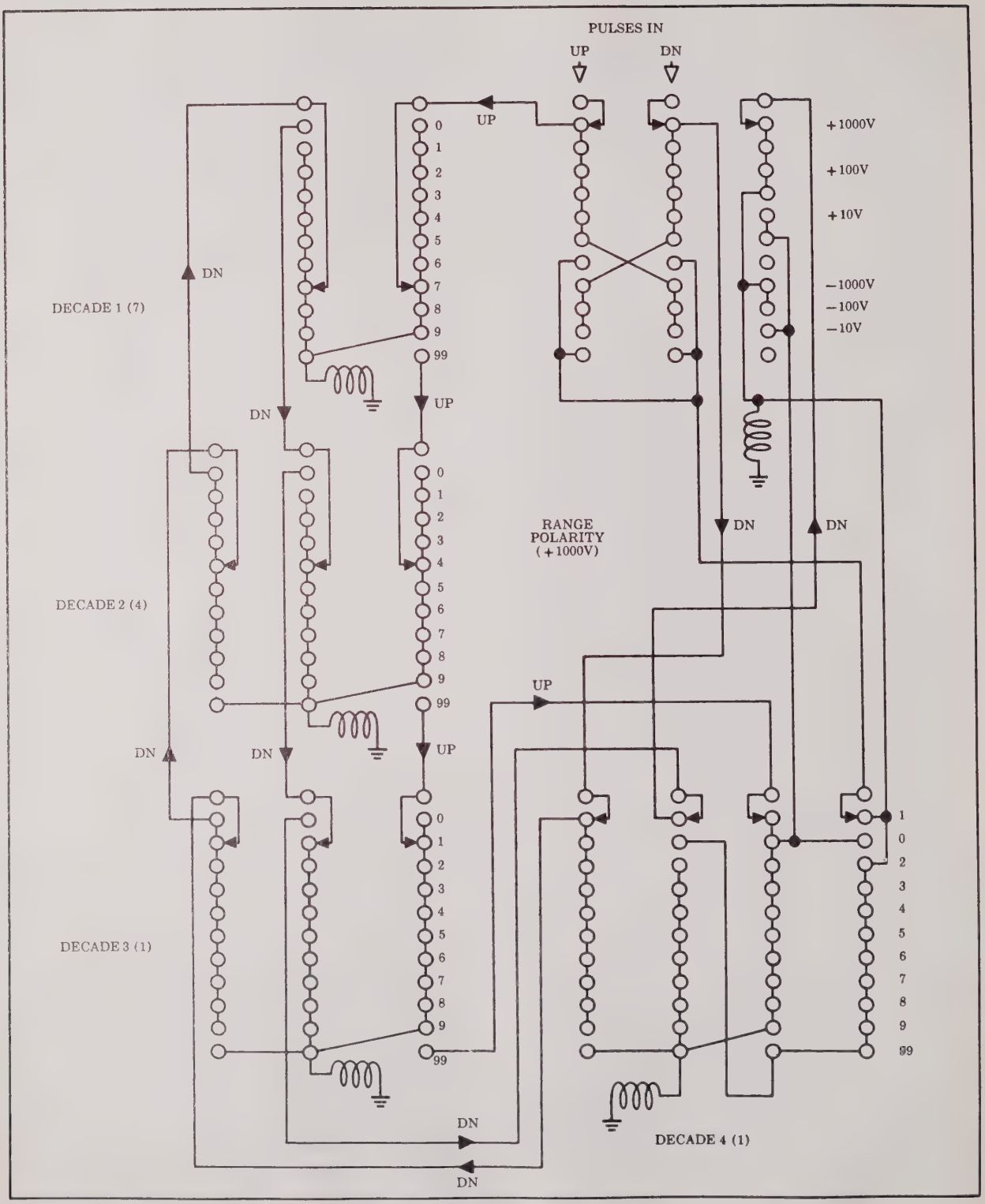


Figure 4-6. Pulse Switching Circuits.

the next numerical decade, and so on, until all decades have been driven to 99. Subsequent "up" pulses are transferred to the range-polarity stepping switch. Since the sequence of steps in the range-polarity switch is 1000 V, 100 V, 10 V, the switch must be driven through the negative positions (as described in the next paragraph) before getting back to the higher range positive position.

3. Down Pulse Routing: "Down" pulses are routed through the stepping switches on decks which are electrically isolated from all other wipers and decks. These pulses enter through the polarity switch in the same manner as the "up" pulses. Assume that the range-polarity switch is in the +1000 V position: "down" pulses coming out of the pulse reversal levels of the range-polarity switch are routed in turn to the fourth, third, second, and first decade. If any switch is in the 99 position, it is first stepped to 0 (1 in the fourth decade), before passing the pulse on to the next decade. Each pulse operates only one stepping switch one step at a time. If all the decades are at any position other than 99, "down" pulses drive the first decade to 0. If "down" pulses continue, they, in turn, drive the second and third decades to 0 and the fourth decade to 1. Continued "down" pulses will drive the range-polarity switch to a lower range until 10 V range is reached. A "down" pulse at this point will drive the fourth decade to 0. Another "down" pulse indicates that polarity reversal is necessary, and the range-polarity switch is driven into the crossover position. The next pulse (which can be either "up" or "down" since the zener supply is now disconnected) drives the four decade to the 2 position, and the following "up" or "down" pulse drives the range-polarity switch into the −1000 V position. At this point, the reading is −200.0 V, and operation is the same as earlier described, except that the zener supply and the "up" and "down" pulse lines have been reversed.

C. ERROR AMPLIFIER: The error amplifier compares the feedback voltage and the unknown DC voltage, which appears at the output of the range attenuator, and issues pulses to drive the stepping switches if the difference between the two voltages is sufficiently large. Phasing of the error amplifier chopper vibration and thyratron plate voltage, which is an AC voltage of power-line frequency, causes pulses to appear on the error amplifier's "up" pulse line when the feedback voltage is less positive than the unknown DC voltage, and causes pulses to appear on the "down" pulse line when the feedback voltage is more positive than the known DC voltage as shown in Figure 4-5. Note that the terms "less positive" and "more positive" apply regardless of whether the unknown and feedback voltages are positive or negative with respect to instrument signal ground. Remember, if the unknown DC voltage is negative with respect to instrument signal ground, the "up" pulse line and the "down" pulse line are interchanged by the automatic polarity switch before the pulses reach the rest of the digital logic circuits. This is necessary to preserve proper sensing throughout the instrument. A detailed explanation of error amplifier theory follows.

1. Chopper: The unknown DC voltage is applied to one stationary contact of an electro-mechanical chopper, K-1, Unit 1, and the feedback voltage is applied to the other stationary contact. The waveform at the top of the vibrating contact is a square wave whose peak-to-peak amplitude is the difference between the unknown voltage and the feedback voltage. If the unknown voltage is less positive than the feedback voltage, this square wave will have a certain phase relationship to the power line sinusoid; and if the unknown voltage is more positive, the phase relationship of this square wave will change by 180 electrical degrees as shown in Figure 4-5. If the unknown input and feedback voltages are equal, the square wave's peak-to-peak amplitude is zero. The absolute voltage values of the square wave are, of course, the absolute values of the unknown voltage and the feedback voltage. However, absolute values of the wave form need not be known for an understanding of amplifier operation since the amplifier's first stage effectively discards the absolute value and passes only the square wave component to the rest of the amplifier. The chopper contacts have a neon tube (V-2) across them to protect the contacts from overload.

2. Calibrate Switch and Rheostat: For calibrating the instrument, the CALIBRATE switch (S-1, Unit 1) permits inserting the known potential of a precise, unsaturated, cadmium standard cell into the amplifier input in place of the unknown input signal. Calibrate rheostats, R-10 (coarse), and R-11

(fine), both of Unit 1, permit adjusting the reference voltage during the calibration procedure.

A small resistance (R-9, Unit 1) is placed between the negative terminals of the standard cell and power ground. The current which passes through the Kelvin-Varley voltage divider also passes through this resistance. The effect of this resistance is to reduce the standard cell voltage as "seen" by the error amplifier to exactly 1.019 volts. This resistance also corrects for the resistance of the input filter choke and for any small error in the Kelvin-Varley bridge at 1019. By using this correction resistance, one standard cell may be utilized to provide an accuracy approaching .01%.

3. First-Stage Amplification: The first stage (V-3) operates in the following manner: The chopper is connected to the grids of the first stage. If the grid connected to the chopper vibrating contact (first grid) becomes more positive with respect to the associated cathode, then plate-current flow in that tube section increases, and both cathodes become more positive. As a result, the second grid becomes more negative with respect to its cathode; less plate current flows in that tube section, and the plate potential becomes more positive. Thus, the input signal has been amplified but its phase has not been inverted. The capacitor in the output plate of this stage removes the DC component from the square wave and, consequently, feeds an AC square wave to the second stage of amplification. The second grid is connected to the output of the range attenuator to properly bias the input stage.

4. Second-Stage Amplification: The second stage (V-4) operates in essentially the same manner as the first stage and further amplifies the signal without inverting its phase. Potentiometer R-18, Unit 1, in the V-4 plate circuit permits adjusting error amplifier over-all gain.

5. Sensitivity Control: The SENSITIVITY control (R-21, Unit 1) is located between the two cathodes of the second stage. Inserting resistance between these two cathodes reduces the coupling and thus reduces the gain of the amplifier. Maximum sensitivity for normal is obtained with the control set fully clockwise for zero resistance.

6. Phase Inverter Stage: This stage includes both halves of V-5. The phase inverter stage converts the single waveform which is capacitively coupled to it from the V-4 plate circuit into two waveforms, 180 electrical degrees out of phase with each other. This is required to generate "up" and "down" pulse-line outputs from the error amplifier.

This stage operates in the following manner: If the grid of V-5A is driven more positive with respect to ground, the V-5A plate will be driven more negative. Thus, V-5A output waveform is 180 electrical degrees out of phase with V-5A grid waveform. V-5A cathode potential becomes more positive and, since V-5A and V-5B cathodes share a common cathode resistor, V-5B cathode also becomes more positive. V-5B grid is held at ground potential and V-5B cathode, becoming more positive, causes V-5B plate potential to become more positive with respect to ground. Therefore, V-5B plate waveform is in phase with V-5A grid waveform.

7. Thyratron Drive Stage: This stage (V-6 and V-7) generates pulses in response to signals from the phase inverter stage to reliably drive the power stage thyratrons. These thyratrons furnish power pulses to operate the stepping switches, even in the presence of fairly strong spurious noise signals. The driver stage is unusual in that the output and input are on a single control grid, pin 1.

Operation is as follows: The outputs of the phase inverter stage are capacitively coupled to the thyratron control grids which are normally biased to cutoff by the resistive network connected to the B- supply. The grid voltage at which the thyratrons fire is essentially governed by the difference between the unknown input voltage and the feedback voltage, the gain of preceding stages, and by the grid bias voltage. The control grid bias is permanently set by fixed resistors, and the over-all amplifier gain (minimum amplifier error voltage input which will cause pulses to be generated at the amplifier output) is adjusted by the gain control potentiometer, R-18, Unit 1. The thyratron plate receives an AC voltage from the power supply transformer so that thyratrons can fire only during the positive half-cycle of plate voltage. Under these conditions, a thyratron can fire only if its control grid signal is in phase with the AC plate voltage. When a thyratron fires, its two grids and cathode assume plate potential (which is positive); the neon tube (V-8 or V-9) in its control grid circuit fires; and a positive pulse is emitted on the asso-

ciated amplifier output line ("up" pulse or "down" pulse line). The thyratrons extinguish on the next half-cycle of power line waveform since the plate potential then becomes negative. The neons, V-8 and V-9, afford excellent electrical isolation between the driver thyratrons, V-6 and V-7, and the power thyratron grids of the next stage; the neons are biased negatively and prevent any unwanted signals or spurious noise on the driver thyratron grids from entering the power thyratron grids; also, when either driver thyratron (V-6 or V-7) fires, the other drive thyratron is blocked from firing because both driver thyratron cathodes become positive.

8. Speed Control Circuit: Thus far, it would appear that the amplifier pulse output occurs at power line frequency. However, this is not desirable, and the speed control circuit is incorporated to keep the driver thyratron from firing on alternate positive cycles of the power line; thus the stepping switch pulsing rate is reduced to one-half of power line frequency. Speed control is achieved by the addition of capacitor C-16, Unit 1, between the driver thyratron cathodes and ground. When a thyratron fires, all the tube elements are at approximately the same voltage. This charges the capacitor to the same voltage as the plate. The thyratron extinguishes when the plate is still somewhat positive with respect to ground. The charge on this capacitor biases the thyratron cutoff beyond control of the grid signal until the charge dissipates through R-35 of Unit 1. The time duration of driver thyratron blocking is governed by the R-C time constant. Increasing the capacitance permits decreasing the stepping switch speed to slower rates, should this ever be desired.

9. Amplifier Test Points: Two test points adjacent to V-5A and V-5B are connected to the plates of this tube to permit observation of error amplifier waveform before it reaches the driver thyratrons. To observe the waveform, connect an oscilloscope between either of these points and chassis ground. Waveform observation is useful in trouble shooting as described in Section VI, Maintenance. Waveform observation also permits gaining greater resolution from the instrument by allowing the user to see how close the instrument is to absolute null. A perfectly clean and symmetrical wave is not to be expected because of electrical noise pickup. When observing the waveform, look out for a very flat top pattern as this usually indicates that error amplifier input signals are large enough to saturate the error amplifier. When this happens, the waveform will not change in response to small changes in the unknown input voltage.

D. ZENER DIODE REFERENCE VOLTAGE SUPPLY: To obtain a reference voltage, the line voltage is stepped up by the reference supply winding of the power transformer. This voltage is rectified by a full-wave semi-conductor diode rectifier, filtered, and regulated intermediately by a gas reference tube. The voltage is then applied through a series resistor to the zener diodes which perform the final regulation. The zener diodes act as voltage regulators because once the zener breakdown voltage is reached, a very constant voltage drop is maintained across the zeners over a wide range of current. The initial operating current must be the proper value to achieve the full benefit of this effect. Relative freedom from reference voltage drift, caused by temperature changes, is achieved by locating the zener diodes is an oven which holds the temperature to $\pm\frac{1}{2}^\circ$ C. However, reference voltage drift may occur with time. The reference voltage is returned to its proper value by following the calibration procedure explained in Section V. The voltage appearing across the zener diodes is not exactly the value required by the instrument, and is dropped to its proper value by the series resistance of the calibration rheostats.

E. STANDARD CELL CHARACTERISTICS: The unsaturated cadmium standard cell provides an E.M.F. of sufficient accuracy for digital voltmeter use; it has a relatively small temperature coefficient and can be inverted. The unsaturated cadmium standard cells used in NLS digital voltmeters supply an E.M.F. which is constant within $\pm 0.01\%$ from 4° C. to 40° C., which may increase by an additional 0.015% between 50° C. and 60° C. The cells used by Non-Linear Systems are virtually free of hysteresis for periods as long as five years. The care and handling of standard cells is discussed in the Maintenance Section of this manual.

F. POWER SUPPLIES: B+ or B— voltages are derived from conventional semi-conductor rectifiers energized by a winding on the power transformer. A time delay relay is used to keep the thyratron plate voltage off until the tubes have

warmed up. A separate power supply is used to furnish positive or negative 28 volts for the readout and printer. A switch on the rear of the instrument selects the proper polarity for various printers. For example, the Hewlett-Packard Model 561B requires −28 volts and the NLS Model 155 Printer requires +28 volts.

Print control in the Model 484A is operated by −28 volts from the supply; the rear-panel polarity switch does not change print-control polarity.

G. PRINTER OPERATION: A print pulse is required to initiate a print cycle in either the H.P. 561B or the NLS 155 printer. Capacitor C-28, Unit 1, is given a charge for this purpose. When this capacitor is discharged, a print pulse has been generated. This capacitor receives its charge (in any print mode) when contacts 5 and 9 of relay K-3, Unit 1, are closed; When the meter comes to a balance, this relay drops out, discharging C-28 through contacts 9 and 1.

The print command is started when relay K-3 is actuated by a negative pulse from the logic circuit of the instrument when it is in the auto mode; a switch provides this pulse for remote or manual operation. This pulse, in turn, energizes transistor Q-1, Unit 1, closing all N.O. contacts on relay K-3. The relay is then held closed by the negative pulses appearing on the "up" and "down" pulse lines through the closure of relay contacts 11 and 7. These negative pulses result from the collapse of the stepping switch coils and are allowed to pass from the pulse lines to relay contact 11, through diodes CR-13 and CR-14, both of Unit 1. These negative pulses keep transistor Q-1 on and charge capacitor C-25 of Unit 1. When the digital voltmeter reaches a balance, the time circuit consisting of C-25, R-54, and R-55, all of Unit 1, and the base of the transistor keep the relay pulled in for approximately 200 milliseconds. When the relay drops out, print command is furnished by the closure of contacts 9 and 1.

A separate positive or negative 28-volt power supply is provided to supply the readout bulbs and harness to the printer. These are connected in parallel at the Elco plug-in strips on the baseboard of the stepping switch assembly (Unit 2). When a light is on in the meter, the same number in the printer harness provides a + or −28-volt signal to the printer, causing that number to print. This supply also operates relay K-3 of Unit 1.

The printer has three modes of operation: Manual, Remote, and Auto.

1. Manual Operation – When relay K-3, Unit 1, is in its N.O. position, open contacts 12 and 8 hold the digital voltmeter in a standby condition. By turning the power switch to the spring-loaded manual position, negative 28 volts is applied to the transistor Q-1 circuit, turning the transistor on and pulling relay K-3 in. When contacts 12 and 8 of the relay are closed, the standby condition is removed and the meter can operate to seek a new balance. Upon reaching a balance, the printer will operate.

2. Remote Operation – Remote operation is achieved by providing a circuit to connector J-2 of Unit 2, Pins 76, 79(N.C.), and 80(N.O.). Any Form C switch or relay may be used remotely to initiate a print command. This relay initiates the print command by charging capacitor C-24 when its N.O. contacts are closed. When it returns to its N.C. position, a negative pulse is furnished to the transistor, turning it on and causing relay K-3 to pull in.

3. Auto Operation – Printer operation is provided by shorting relay K-3 of Unit 1, contacts 11 and 7 N.O. and contacts 12 and 8 N.O. when the POWER switch is set at AUTO PRINT.

Any error in the amplifier can now actuate the stepping switches. The resultant negative pulses, through shorted contacts 11 and 7, will cause relay K-3 of Unit 1 to close and stay closed until approximately 200 milliseconds after the meter balances. When the relay is closed, capacitor C-27 of Unit 1 is charged negatively from the B— supply through relay contacts 6 and 10. When the relay drops out to provide a print pulse, capacitor C-27 of Unit 1 provides a negative bias to the 5696 thyratrons through the time circuit of capacitor C-27 and resistor R-40, both of Unit 1. This keeps the 5696 thyratrons biased for approximately 400 milleseconds, allowing time for print operation.

The instrument has then completed its cycle and is ready to take a new reading and repeat the cycle.

CALIBRATION

Section Five

This section discusses the several adjustments which are made to standardize the instrument.

I Preliminary Steps

A. GAIN SETTING: For best results, the digital voltmeter should be operated with the amplifier gain set at one digit. If the amplifier gain is not set high enough, the resolution of the instrument will be too low. On the other hand, excessively high amplifier gain settings may cause instability of the readout display.

Remove the front-panel cover button over the fine and coarse calibration adjustment screws on the front panel. Rotate the OPERATE-CALIBRATE control (S-1, Unit 1) to CALIBRATE.

After the visual readout has come to a balance, use a screwdriver and slowly turn the FINE calibration adjustment screw, R-11 of Unit 1, in a counterclockwise direction. Observe the amount of the decrease in the readout display. If the display de-

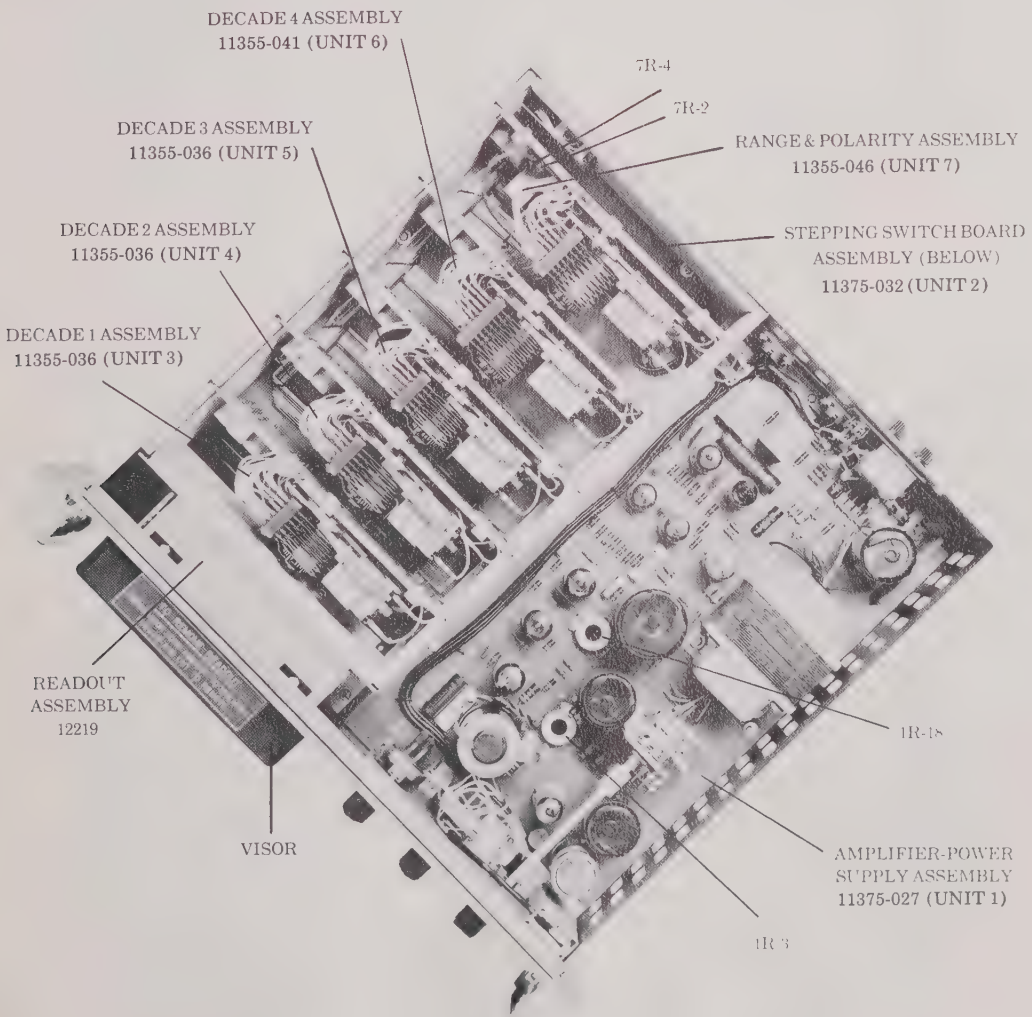


Figure 5-1. Top View of Digital Voltmeter with Cover Removed.

creases in steps of one digit and does not become unstable, no adjustment of amplifier gain is necessary. If slowly rotating this rheostat in a counterclockwise direction results in a decrease of two or more digits in the right-hand window, the amplifier gain should be increased by slightly turning the slotted GAIN control potentiometer, R-18, Unit 1, on the amplifier in a clockwise direction. See Figure 5-1 for location. Again, observe the number of digits by which the readout display decreases when the FINE calibration rheostat shaft is slowly turned counterclockwise. Repeat the amplifier gain adjustment if necessary to obtain a readout display decrease of one digit in the right-hand window. If instability develops in the readout display, turn the amplifier gain control counterclockwise until the instability just disappears and the readout display decreases in steps of one digit in the right-hand window as the FINE calibration rheostat adjustment is slowly turned counterclockwise.

B. HUM CONTROL ADJUSTMENT: If the hum control has not been properly adjusted, considerable error in calibration accuracy will occur. The hum control has been accurately set at the factory and it need not be reset unless out of adjustment. Be certain that any new input tube used has been properly aged before setting the hum control.

Procedure: To adjust the hum control (R-3 of Unit 1), which is located on the component side of the amplifier chassis, take the following three steps:

1. Connect the chassis to a good earth ground (the third pin of the power cord connected to the chassis). Turn on the digital voltmeter and allow it to warm up for fifteen minutes. Connect an oscilloscope between either of the two test points as shown in Figure 5-2 and ground. Calibrate the oscilloscope in terms of one digit error. To do this, turn the CALIBRATE-OPERATE switch, S-1, to CALIBRATE and slowly back off the FINE calibration

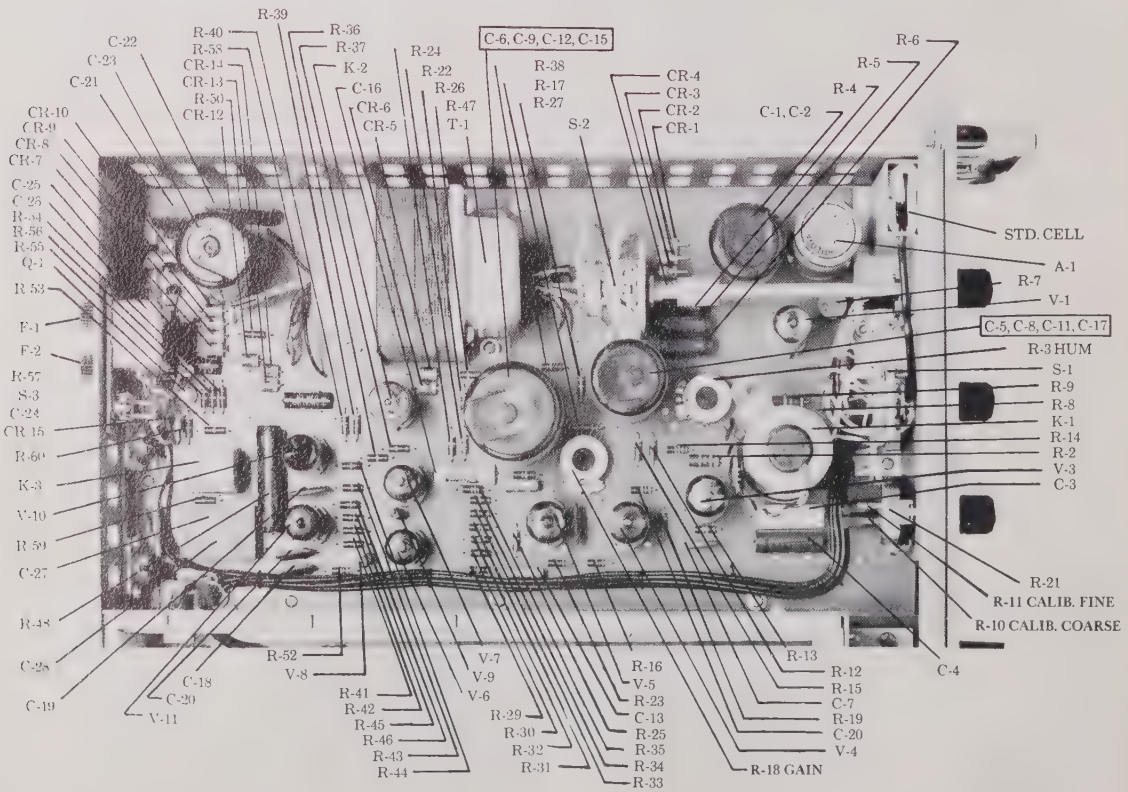
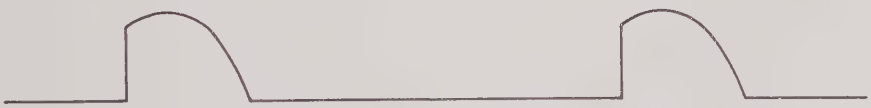


Figure 5-2. Amplifier-Power Supply (Unit 1) with Cover Removed.

(A) ERROR SIGNAL AT TEST POINTS.



(B) "UP" AND "DOWN" PULSES AT 2D21 GRID.

(C) POWER THYRATRON OUTPUT PULSES WHEN STEPPING SWITCH COIL CIRCUIT IS OPEN CIRCUITED.

(D) PULSE ACROSS STEPPING SWITCH COIL.

Figure 5-3. Typical Pulse Waveforms.

adjustment, R-11, Unit 1. Note the amount of error signal on the oscilloscope just prior to the time that the thyratron fires. This error signal is equivalent to one digit if the gain is properly set as described at the beginning of this section and the SENSITIVITY control is advanced fully clockwise. The error signal is the vertical distance on the oscilloscope trace between the end of the sloped portion of the square wave and the beginning of the straight horizontal portion, as shown in Figure 5-3(a).

2. With the meter POWER switch set at OPERATE, short the input leads to obtain a reading of ±0.000. Switch to STANDBY. By hand, step the range-polarity switch (K-1 of Unit 7) until the meter reads +00.00. Adjust the hum control, R-3 of Unit 1, for "0" error signal as displayed on the oscilloscope. The hum control is now properly set.

3. Check the error signal for all ranges (+00.00, +0.000, −000.0, −00.00, −0.000, and +000.0), stepping the range-polarity switch by hand. Do not move the hum control. The error signal for all range positions should be less than one-half digit. If the error exceeds this amount, there are two sources of trouble: (1) excessive hum pickup, or (2) excessive grid current. Check all shields and ground leads. Replace the 5751 input tube. Do not substitute any other type tube.

C. STANDARDIZATION ADJUSTMENT: The calibration procedure described enables the instrument to be standardized to an accuracy far exceeding the 0.1% accuracy normally possible with one standard cell, and one millivolt sensitivity. In order for the correct setting to be exactly "1019", several corrections must be made: (1) the standard cell voltage will generally differ slightly from 1.0190 volts: (2) the input filter choke L-1 has a resistance of approximately 4000 ohms; (3) the feedback signal might differ slightly from 1.019 V, and still be well within the necessary tolerance. The current which passes through the Kelvin-Varley bridge (0.2 ma) also passes through R-9 of Unit 1. This produces a small voltage which reduces the standard cell voltage as compared by the error amplifier and corrects for the errors listed in this paragraph.

Before making any adjustment, make certain that the gain and hum controls are properly set, and that the instrument is connected to a good earth groud. After this check has been made, hold the CALIBRATE switch in the CALIBRATE position, and slowly back off the FINE adjustment control, stopping each time the meter changes reading. The meter should drop one digit each time. If the reading drops more than one digit or exhibits instability, adjustment of the internal gain control will be necessary, as described at the beginning of this section. Continue backing off the FINE adjustment control until ten steps have been satisfactorily completed. Once it has been ascertained that the gain adjustment is proper, the instrument may be accurately standardized.

Connect a bank of nine standard cells whose accuracy is known to be at least 0.01% to the input.

CAUTION

Be certain to take into account the internal resistance of the standard cells. The Model 484A has an input resistance of 10 megohms and with a 9-volt signal will draw 0.9 microamperes.

While holding the CALIBRATE-OPERATE switch in the CALIBRATE position, slowly advance or retard the COARSE adjustment control until a reading of 1017 or 1018 is reached. For the final adjustment, advance the FINE adjustment control until the reading just steps to 1019 and then stop. The meter is now standardized.

NOTE

1. The decimal point may appear in any location during the standardization procedure because the DC voltage range-change circuitry becomes de-energized during this operation.

2. This procedure standardizes the internal reference voltage supply against a highly accurate and stable standard cell.

D. FEEDBACK VOLTAGE LINEARITY TEST: One of several factors which can affect the accuracy of measurements made with digital voltmeters is the linearity characteristic of the Kelvin-Varley voltage divider. The digital Kelvin-Varley circuit develops a known feedback voltage within the meter to which the unknown input voltage is compared during measurement. Many methods for testing linearity of the digital Kelvin-Varley voltage divider exist, but the method described in this section has been found to be most satisfactory. It is assumed that the error amplifier gain is properly adjusted before the test is started.

Section V
CALIBRATION

Only one piece of precision test equipment is required, a variable voltage divider having an accuracy five to ten times better than that of the digital voltmeter under test. Connect a suitable 10-volt reference to the external (Ratio) connector, 1J-3 (Pin A, positive; Pin C, ground). Connect this same reference to the input of the voltage divider. Connect the input cable of the digital voltmeter to the output of the voltage divider. Observe the shielding and grounding rules given in Section III. Adjust the standard divider to a reading of 00000; the digital readout should display zero in each window. Adjust the standard voltage divider to read 99990; the visual readout display should be 9 in each window. These two readout displays must be obtained for the indicated standard divider settings. If the instrument displays digits other than indicated in this paragraph for these two end points, an improper circuit condition exists, and must be located and corrected before the tests are continued. Next, set the standard divider for various readings such as: .89990, .79990, .69990, .08990, .07990, .00890, .00790, .00080, .00070, etc.

The digital instrument visual readout displays should be equal to the standard divider settings, plus or minus one digit.

One very desirable feature of the ratiometer method of testing voltage divider linearity is that deviations as large as 20% from the nominal value of reference voltage have no significant effect upon test accuracy. This is true because the same voltage is furnished to the input of the internal voltage divider as well as the input of the external standard voltage divider. Thus, for equal settings of the two voltage dividers, the output voltages are equal if the input voltages are equal.

As an alternative method, the digital voltmeter linearity can be tested by connecting a stable and finely adjustable DC voltage source to its input terminals, and monitoring this input voltage with a precise, laboratory type potentiometer. It will suffice to vary the input voltage and observe whether the digital voltmeter readings are proportional to the precision potentiometer readings within the accuracy limitations of both measuring devices.

The disadvantage of this method is that uncompensated drifts of the voltmeter or precision potentiometer voltages during the test will give a false indication that the digital voltmeter linearity is not within tolerance.

E. RANGE UNIT ADJUSTMENT: The range unit will require scale factor readjustment only if the range unit resistors change their ohmic value or if the electrical loading of the unit output taps changes. The adjustment method here described requires several accurate voltage dividrs and a stable DC source. This method permits accurate range unit scale factor adjustment regardless of any inaccuracies present in the digital Kelvin-Varley voltage divider. This is because the divider is always brought back to the same position (same numerical display on digital voltmeter, ignoring decimal point location) when the correspondence of scale factors on each range is checked. As with any other test, proper shielding and grounding techniques must be followed to prevent electrical noise pickup from interfering with the instrument's stability and resolution. Also, in checking each range, best accuracy is achieved when the test voltage used is as close to full scale for that range as is practical. The precision voltage divider used in the range unit adjustment procedure must be compensated for the electrical loading effect of the digital voltmeter.

The precision voltage divider accuracy should be five to ten times better than the accuracy to which the range unit is to be adjusted.

Access to the range trim potentiometers referred to in the following instructions is gained by removing the top cover. These potentiometers are on the range and polarity plug-in board assembly 11350-046 at the back of the instrument and are identified by 1000 V and 100 V markings on the printed circuit range board.

ADJUSTING THE 100-VOLT RANGE SCALE FACTOR

1. Connect the input terminals of a 10 to 1 precision voltage divider to a stable but not necessarily accurate source of 95 to 99 volts.
2. Connect the input terminals of the digital voltmeter under test to the input of the voltage divider; observe the readout display and waveform at the error amplifier test points.
3. Move the input terminals of the digital voltmeter to the output terminals of the voltage divider; observe the readout display and error amplifier waveform.
4. The 100-volt range is properly adjusted when

the readout display in Step 3 is exactly equal to 1/10 of the readout display observed in Step 2 (for example: 95.93 in Step 2, compared to 9.593 in Step 3) and when the error amplifier waveform amplitude and phase are similar to that observed in Step 2. If this correspondence is not present, adjust the 100-volt range trim potentiometer.

ADJUSTING THE 1000-VOLT RANGE SCALE FACTOR

1. Connect the input terminals of a 100 to 1 voltage divider to a stable source of DC voltage as close to 999 volts as practical (lower voltages above 200 volts can be used, but accuracy is not as good as when higher voltages are chosen).
2. Connect the input terminals of the digital voltmeter under test to the input terminals of the voltage divider; observe the readout display and waveform at the error amplifier test points.
3. Move the input terminals of the digital voltmeter to the output terminals of the 100 to 1 voltage divider; observe the readout display and error amplifier waveform.
4. The 1000-volt range is properly adjusted when the readout display in Step 3 is exactly one hundredth of the readout display observed in Step 2 (for example: 982.3 in Step 2, compared with 9.823 in Step 3) and when the error amplifier waveform amplitude and phase are similar to that observed in Step 2. If this correspondence is not present, adjust the 1000-volt range trim potentiometer.

MAINTENANCE

Section Six

This section discusses the preventive and corrective maintenance measures which should be taken to assure continued satisfactory operation of the 484A Digital Voltmeter. In general, such steps as lubricating the stepping switches, tensioning readout bulb contacts, cleaning lucite number panes, tightening set screws as well as assembly screws, and keeping the whole instrument clean are typical preventive maintenance procedures. If this type of maintenance is not neglected, the digital voltmeter can be expected to render years of service. On the other hand, when a definite malfunction occurs, corrective maintenance steps need to be taken. For the most part, the troubleshooting table as well as other information within this section will fill the need for corrective maintenance.

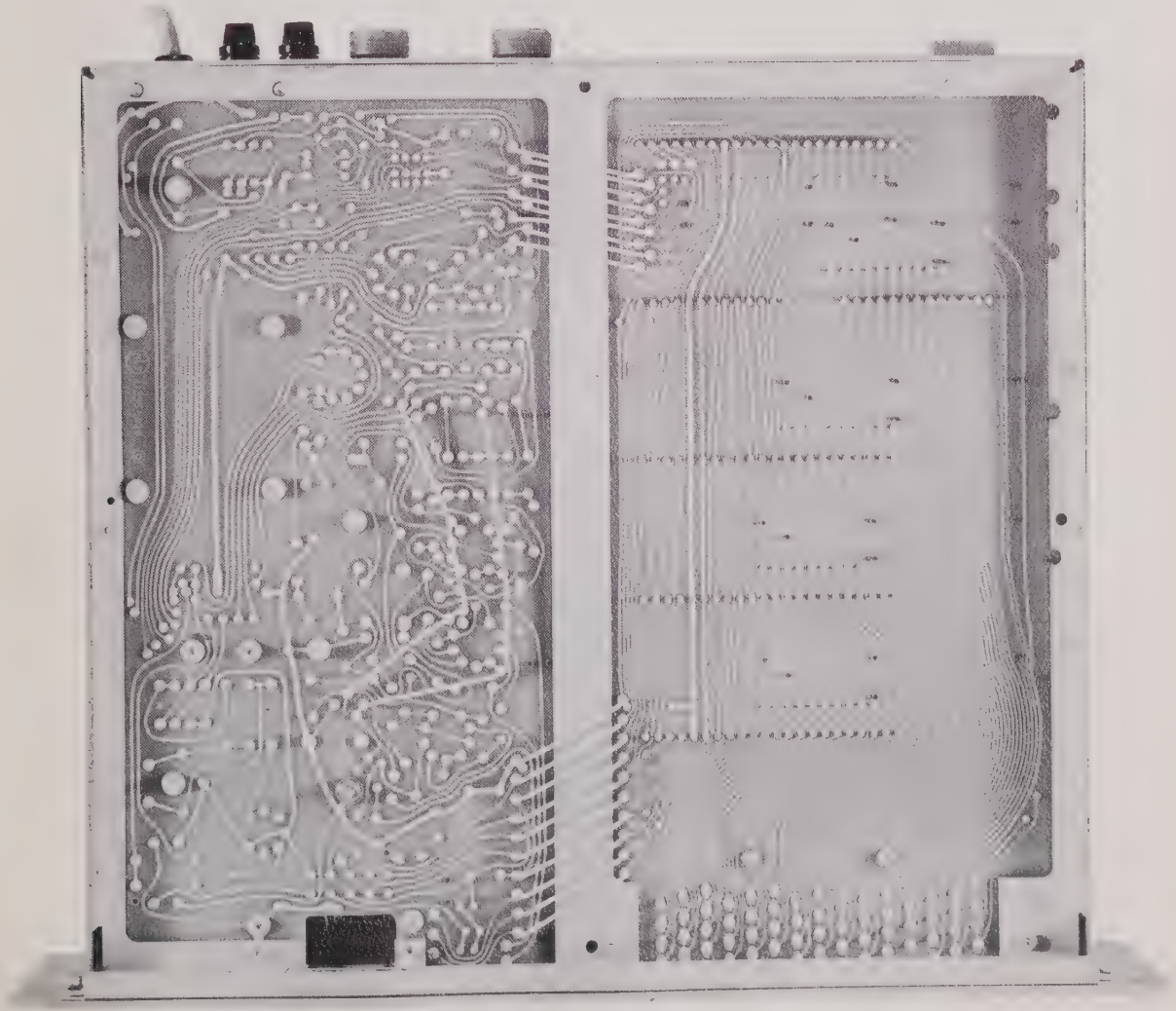


Figure 6-1. Bottom View of Digital Voltmeter with Cover Removed.

Section VI
MAINTENANCE

I Access for Maintenance

The electronic and stepping switch assemblies may be reached by removing the two screws at the rear of the top cover. The plug-in stepping switch assemblies can be individually removed for lubrication or maintenance by simply pulling up on the jointed lifting lever located at the center top of each plug-in board. By removing the bottom cover in the same manner as the top, the soldered side of all printed circuits on the amplifier and stepping switch main boards are made accessible. See Figure 6-1 in this section as well as Figure 5-1 in the Calibration Section.

II Test Equipment

Perhaps the most useful test instrument is the digital voltmeter being tested. The readout display almost always provides an indication of the likely source of malfunction. Note that most of the troubles listed in the trouble-shooting table at the end of this section make reference to the condition of the readout display. An ordinary oscilloscope will be found useful for tracing amplifier output pulses. Resistance and continuity checks can be made with conventional volt-ohmmeters or with vacuum-tube voltmeters, if the question of circuit loading is taken into account. Remember that continuity checks of circuits containing diodes should be made with an awareness of polarity; diodes will conduct in one direction, but not in the other.

III Component Replacement

A list of all replaceable parts is included in Section 7, Parts List. However, since many of the components are standard electronic radio parts, we suggest that the user purchase them from his local dealer if practical. NLS manufactures most of the mechanical parts, and some of the components used in the instrument. When ordering a mechanical part, be sure to describe it completely; also, furnish the model and serial numbers of the instrument to which the part is to be fitted. Our nearest field engineer or sales and service representative will answer questions about replacing parts. A list of representatives will be found in the appendix to this manual. Parts information is also obtainable from the Service Department at the home office of Non-Linear Systems, Inc. in Del Mar, Calif.

IV Parts Identification

The Model 484A Digital Voltmeter has two main assemblies; the electronics main board (Unit 1), and the stepping switch main board (Unit 2). Thus a resistor identified in this manual as R-1, Unit 1, would be part of the electronics board, as shown in

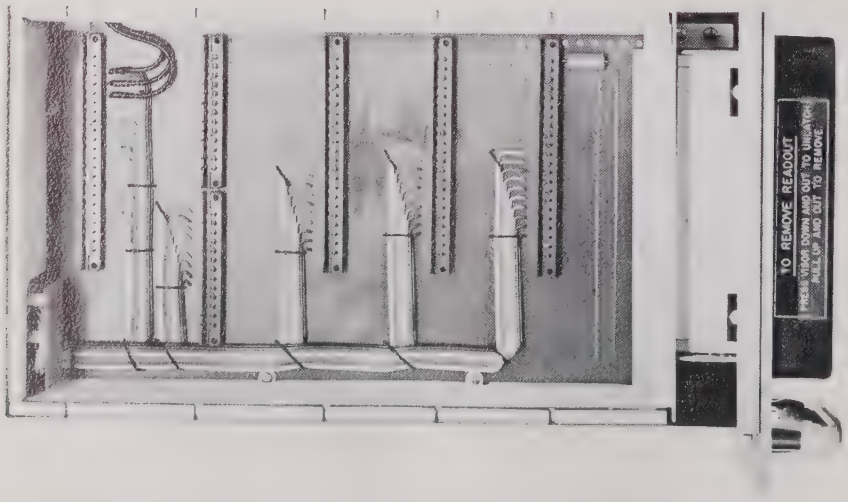


Figure 6-2. Stepping Switch Board Assemblies, Top View with Switches Removed.

Figure 5-2 in the Calibration Section. The stepping switch main board, which contains connectors for the stepping switches, is identified as Unit 2, and includes the readout. This board is shown in Figure 6-2. In addition, the instrument has five plug-in stepping switch assemblies, each with its own small printed circuit board with decade resistors; three of these stepping switches are physically identical and, therefore, interchangeable. The Model 484A stepping switches are shown in Figure 6-3.

A. ELECTRONIC ASSEMBLY: Error Amplifier – This amplifier compares an unknown input voltage with the known feedback voltage from the stepping switch assembly. Whenever these two voltages are unequal, a square wave error signal is generated by the chopper. This signal is then amplified and may be observed with an oscilloscope. The oscilloscope is connected between ground and either one of the two error-signal test points on the error amplifier in one of the plate circuits of the phase-

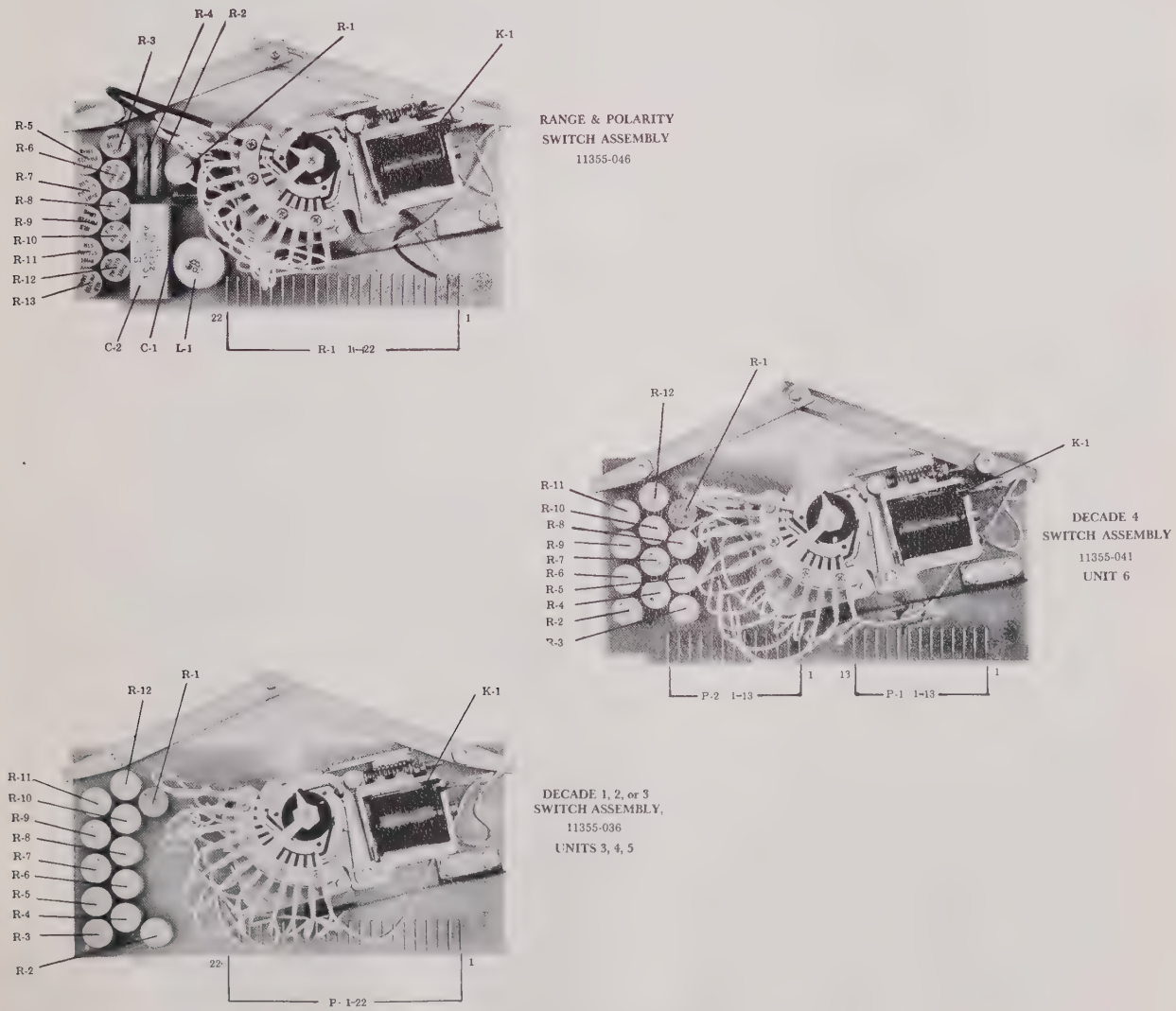


Figure 6-3. Stepping Switch Assemblies, with Lifting Handles in Raised Position.

inverter vacuum tube. When the digital voltmeter is at the balance, the error signal becomes a straight line, modified somewhat by hum and noise pickup. If no error signal is observed at the test points, trace back through the preceding stages to the output of the chopper until the error signal once more becomes evident. Faulty components or tubes may need to be replaced to regain signal at the amplifier test points.

Existence of "up" or "down" pulses generated by 5696 thyratrons in the amplifier can be determined by observing which of the two neon bulbs are glowing. When a plus polarity sign is displayed in the readout, "up" pulses are being generated if the right-hand (as seen from the front of the instrument) neon bulb is glowing. "Down" pulses are being generated if the left-hand bulb is glowing. These pulses at the grid of the 2D21 take the shape shown in Figure 5-3(b) in the Calibration Section. These amplifier output pulses trigger one of the two 2D21 thyratrons. Pulses from the 2D21's are routed to the logical switching circuits in the stepping-switch assembly. If the stepping switch circuit is open and the switches do not step, the pulses from the power thyratrons will resemble Figure 5-3(c) on the oscilloscope screen. The pulse waveform across the coil of a properly operating stepping switch resembles Figure 5-3(d) on the oscilloscope screen.

Power Supplies – Two power supplies are used; one furnishes B+, B–, and amplifier filament power. The thermal time-delay withholds plate voltages from the thyratrons until filaments are fully heated. A separate positive, negative, 28-volt power supply furnishes power for the readout lamps, printer, and print control.

ZENER REFERENCE SUPPLY – This reference supply has very few components and is normally trouble-free. Details of its operation have been described in the Theory Section. Access to the zener diodes is gained by disassembling the crystal oven. If it is necessary to replace the zener diodes, make certain that the red dot (positive terminal) is connected to pin 8 of the octal socket.

THE STANDARD CELL – The standard cell may be reached by removing the front panel of the digital voltmeter. Care should be taken to avoid shorting the terminals of this cell – even with the fingers. If the cell is to be changed, the voltmeter will need to be restandardized, as described in the Calibration Section.

Several precautions are to be observed in the maintenance of standard cells. First of all, care should be taken to avoid drawing current from standard cells. As much as 100 microamperes may be drawn for several minutes without permanently affecting the E.M.F., although current drain should be low as possible and for only short periods of time. The E.M.F. of short-circuited cells should be accurately measured and observed before they are used again. A cell which has been short-circuited for a half hour may require a month to recover to within 0.01% of its original value – if it does so at all. The best practice is simply to replace any cells which have been short-circuited. Approximately 0.001 microampere is drawn while operating the CALIBRATE control. A 470,000 ohm protective resistor (R-8, Unit 1) in series with the standard cells furnishes protection against vacuum-tube structural failure, and the like.

Standard cells should be stored vertically, right side up. If inverted for extended periods, E.M.F. changes may result. The cells are best kept at a normal room temperature or slightly below. If stored at 80° F., an 0.01% decrease in E.M.F. will occur after one year. In general, cells should not be subjected to temperatures above 130° F. or less than 39° F. Tests show that cells will stay within ±0.01% of room temperature E.M.F. when stored in an environment as cold as –15° C. (3.2° F). The E.M.F. may drop to less than 1 volt in colder environments of –30° C (–22° F). When again exposed to room temperature, the E.M.F. normally recovers to within 0.1% of original room temperature E.M.F. within six to twelve minutes. In a few more minutes, the cell will recover fully.

B. STEPPING SWITCH PLUG-IN ASSEMBLIES

1. Stepping Switch Lubrication–Periodic lubrication is essential. To lubricate most points, a #4 Artist's Sable Rigger brush is used. As listed in the lubrication chart, a "dip" is the amount of lubricant retained on the brush when it is dipped ⅜" into the lubricant and lightly scraped on the edge of the container to remove excess. There should not be enough lubricant on the brush to form a drop. See Figure 6-4 for location of parts.

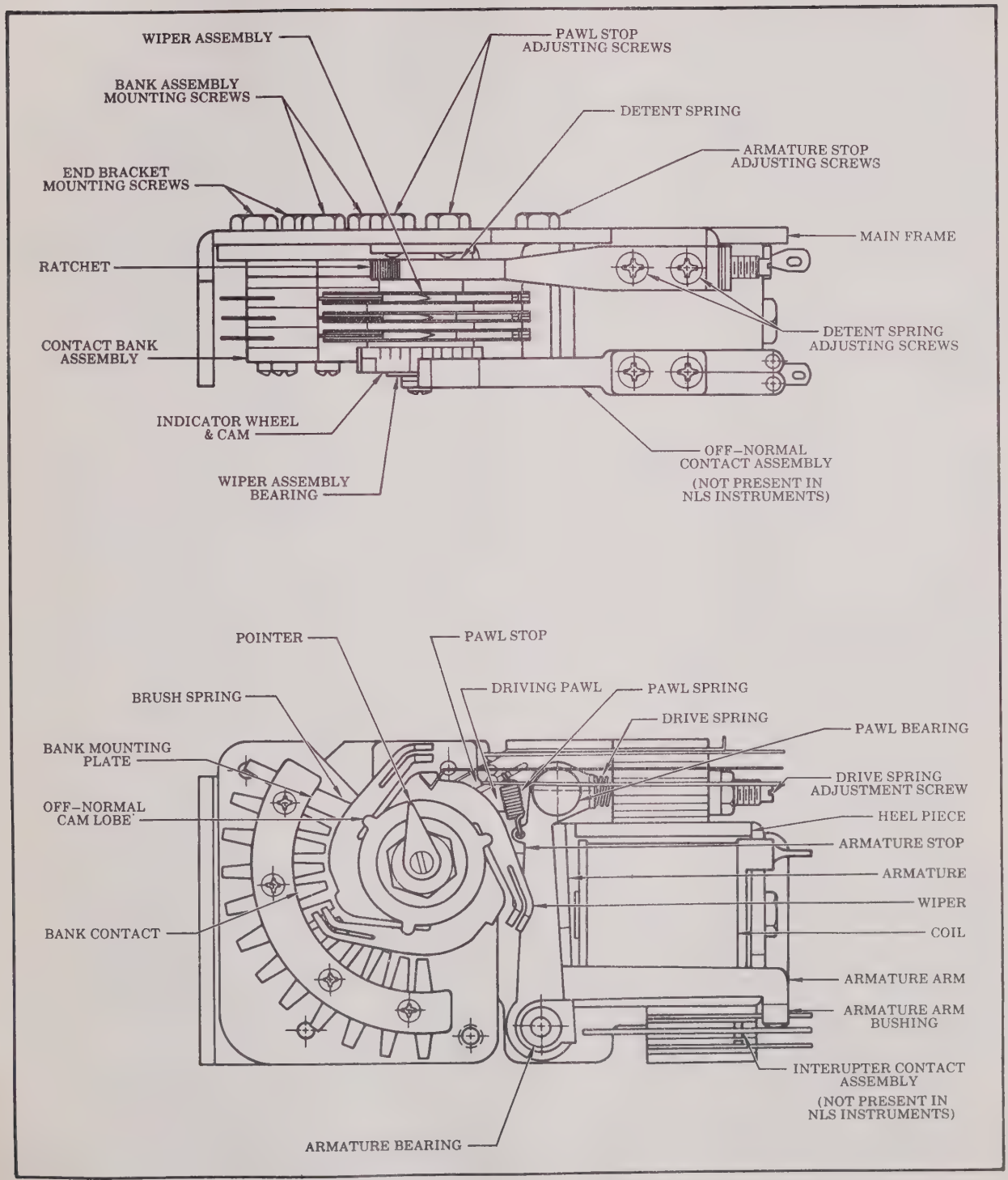


Figure 6-4. Identification of Principal Stepping-Switch Parts.

LUBRICATION CHART

LUBRICATION POINT	TYPE LUBRICANT	LUBRICATION PROCEDURE
Wiper assembly bearing	Clock oil or equivalent	Apply one dip near the pointer
Each pair of wiper contacts	Clock oil or equivalent	Draw a strip of bond paper, treated with two dips on each side, through the wiper contacts. Rotate assembly to distribute lubricant.
Inner sides of each pair of wipers where brush springs ride	Clock oil or equivalent	Apply one dip of oil at the point indicated.
Armature bearing	Light mineral oil	Apply one dip to each side of bearing.
Pawl bearing	Light mineral oil	Apply one dip to each side of bearing.
Pawl spring hooks	Light mineral oil	Apply one lean drop to the hooks at the eyelets.
Ratchet teeth	50-50 mixture (by volume) of powdered mica and clock oil	Apply two dips to the ratchet teeth, rotating to distribute lubricant.

No lubrication is required prior to placing into service unless shelf life has exceeded 3 months. Thereafter, lubricate at the following intervals:

at 25,000 revolutions or 3 months, whichever comes first;
at 75,000 revolutions or 6 months, whichever comes first;
at 200,000 revolutions or 9 months, whichever comes first;
at every additional 200,000 revolutions or 9 months thereafter, whichever is the more frequent.

After the stepping switch assembly has operated for many hours, a black deposit forms on the decade resistor boards and adjacent areas. This is the result of normal stepping switch wear. If regular lubrication is performed, the amount of this deposit will be lessened. However, if the switches are not lubricated frequently enough, the amount of deposit may become excessive and will need to be wiped off.

2. Stepping Switch Adjustment – The Type 11 switch will hold adjustment for considerable life. Aside from lubrication, no attention is required until life has reached ½ million revolutions. At this point and at at every ½ million additional revolutions thereafter, an adjustment inspection needs to be made.

a. Wiper Assembly – Inspection: With wipers on contact No. 1, rock wiper assembly gently forward and reverse by hand. Note contact area on which wiper tips play. The tips must play within the limits shown on Figure 6-5.

Readjustment: If tips play beyond forward motion limits, the pawl stop should be readjusted by moving it slightly toward the pawl to check excessive forward motion of the wipers. The pawl stop face should be carefully aligned to rest against the pawl as flatly as possible.

If tips play beyond reverse motion limits, the detent spring should be readjusted by moving it slightly toward the ratches to check excessive reverse motion of the wipers. The detent should also drop freely into each tooth when the switch is manually stepped.

These adjustments provide near-zero wiper play with tips approximately centered between inspection limits as shown in Figure 6-5.

b. Armature Backstop – Inspection: The armature should rest against the backstop. Inspect by

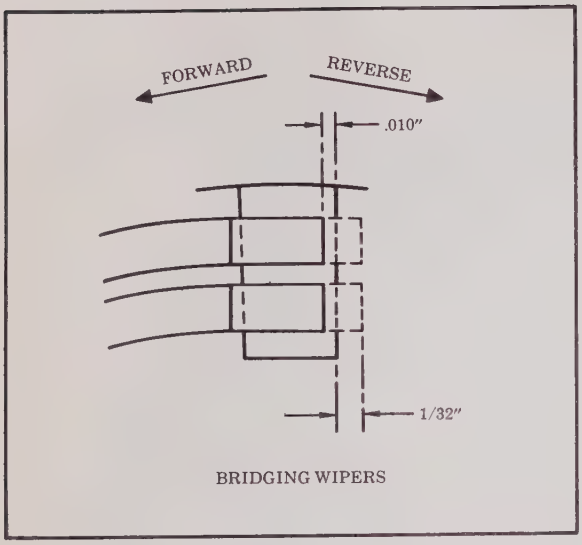


Figure 6-5. Stepping Switch Wiper Tip Travel Limits.

inserting a .0015" thickness gauge between the armature and the stop. The gauge should drag on withdrawal.

Readjustment: If the gauge has no drag on withdrawal, the backstop needs to be readjusted. It should be moved slightly forward to touch the armature but not far enough to lift the pawl from the pawl stop. Recheck for gauge drag, and for manual stepping with positive detent spring action, after tightening stop screws.

To have the armature and pawl strike their stops with approximately equal force is considered an ideal adjustment.

C. DIGITAL READOUT MAINTENANCE: The only maintenance step normally required for the digital readout is lamp bulb replacement. However, if readout plates require cleaning because of extremely adverse dust or humidity conditions, clean them with commercial isopropyl alcohol and lint free paper, such as Kimwipes 900-L, manufactured by Kimberly Clark, Neenah, Wisconsin. Readout plates can be slid from their grooves after removing either structural end plate from the readout. Readout plate and bulb placement is shown on the main schematic at the end of the manual. Figure 6-6 will also be helpful. However, to avoid any possible error, record the location of each readout plate as it is removed. As the readout is re-assembled, avoid reversing or inverting the readout plates, particularly 1, 0, 6, 8 and 9. The engraved side of the readout plates should face the rear of the readout. Avoid scratching the readout plates and polaroid filter. Also, if the polaroid filter is removed, it must be reinstalled with the proper side inward. Hold a piece of shiny metal against the filter sheet and look through it at the metal. Turn the filter over and, again, look through at the metal. The correct side of the filter to face the rear of the readout shows the least metal glare.

To replace burned-out lamps in the digital display, remove the readout, including the black visor. This is readily done by pressing downward on the top of the visor while exerting a gentle forward pressure. The readout and visor assembly will then disengage itself at the top by about 1/8 inch from the front panel. The assembly is then brought up slightly and out of the instrument.

When the readout has been removed, the bulbs may be extracted for inspection. Figure 6-6 shows the readout with bulbs correctly installed.

D. KELVIN-VARLEY VOLTAGE DIVIDER: Any deficiencies which develop in the Kelvin-Varley voltage divider should become evident during a linearity test. However, most deficiencies will appear during normal use of the instrument, or during a test in which the input voltage is slowly varied from zero to full scale on the instrument's lowest range (observing the error amplifier waveform during such a test is helpful). Two sorts of deficiencies are listed:

1. If the instrument either oscillates at some point in its range, or reads all nines, look for open-circuited resistors, broken wires, or stepping-switch contact failure.

2. If, as the input voltage is slowly increased, the readout display skips a number, it is probable that a resistor associated with the old and new displayed numbers is too low in ohmic value.

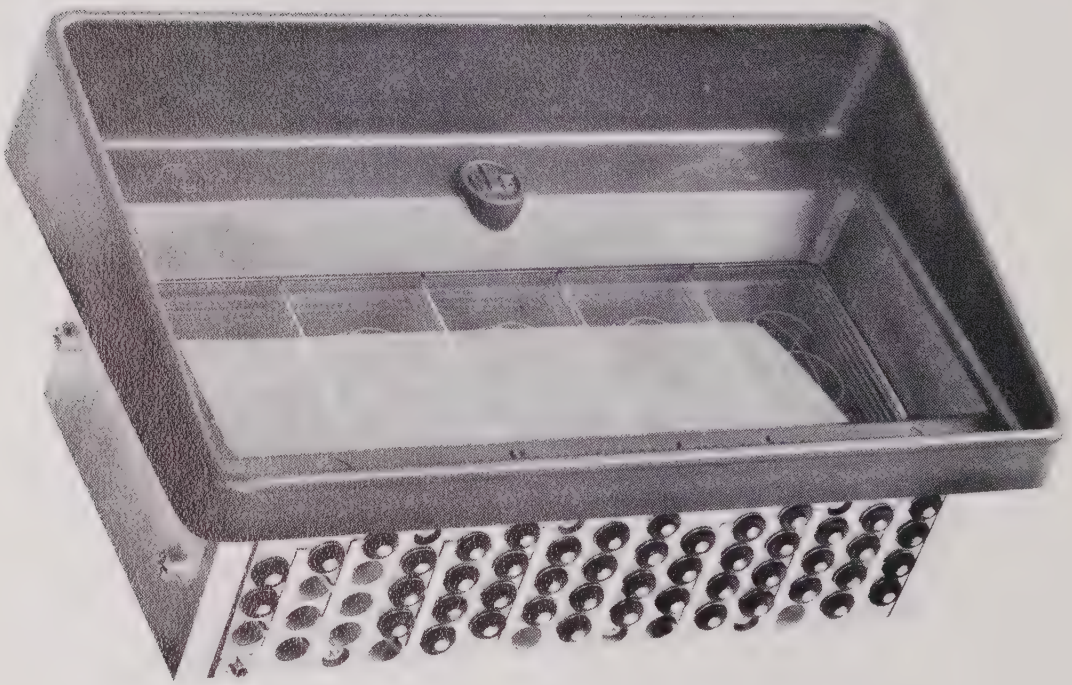


Figure 6-6. Readout, Showing Bulbs Correctly Installed.

TROUBLESHOOTING CHART

SYMPTOM	PROBABLE CAUSE	REMEDY
Entire visual readout fails to light up	Power switch in off position.	Turn on power switch.
	No 110V AC line voltage	Trace line failure
	Power cable defective	Repair or replace cable
	Fuse blown	Replace fuse
	No −28 V	Check for −28 V at various points.
	Power transformer open circuited.	Replace power transformer.
Some characters in the visual readout display fail to light up	Defective readout indicator lamp	Replace lamp.
	No −28 V available at center contact of lamp	Trace −28 V line through associated stepping switch.
Unstable readout display	Amplifier gain too high	Adjust amplifier gain.
	Excessive ripple on unknown DC input voltage	Provide suitable filter between unknown voltage source & digital voltmeter leads.
	Stray noise voltage being picked up	Connect chassis of digital voltmeter to good earth ground. Use shielded leads.
	Microphonic or gassy 5751 (1st stage amplifier) tube	Replace 5751 tube.
	Unstable 5696 thyratron in amplifier.	Replace 5696 tubes.
	Faulty reference voltage circuit connections	Check connections.
	Decade stepping switch contacts making intermittent contact	Increase wiper tension
	Reference voltage supply noisy or not regulating	See section of text dealing with reference supply.
	Noisy or partially shorted resistors in range attenuator or Kelvin-Varley divider	Replace faulty resistors.
	Faulty ground circuit connection inside instrument	Find and repair faulty connection.

TROUBLESHOOTING CHART (continued)

SYMPTOM	PROBABLE CAUSE	REMEDY
Readout display decreases in steps or more than one digit when input voltage is decreased very slowly.	Low Amplifier gain	Adjust amplifier gain.
	Low Amplifier gain	Check amplifier tubes & replace any found to be weak or defective.
	Amplifier saturated with noise	Observe effective shielding and grounding procedures.
		Replace amplifier tubes.
Visual readout display increases and stays at full scale when input voltage is less than full scale.	Feedback voltage missing at chopper	Re-establish continuity of reference voltage circuit.
	Defective chopper	Replace chopper
Readout display will not increase.	No error signal	Replace chopper
		Make point-to-point check of amplifier with oscilloscope.
	"Up" pulses missing	Check range attenuator output voltage line from range stepping switch to pin 4 of chopper.
		Replace type 5696 or 2D21 tube.
		Replace defective neon tube in amplifier assembly.
		Check feedback voltage line from decade one switch to chopper.
	Low line voltage (Less than 105 V AC)	Remedy cause of low line voltage or employ a step up transformer.
Readout display will not decrease.	No error signal	Replace chopper.
		Make point-to-point check of amplifier with oscilloscope.
	Low line voltage	Correct cause of low line voltage.
	"Down" pulses missing	Check feedback voltage line from decade one switch to chopper.
		Replace type 5696 tube in amplifier and 2D21 in power supply.

TROUBLESHOOTING CHART (continued)

SYMPTOM	PROBABLE CAUSE	REMEDY
Readout display will not decrease.		Replace defective neon tube in amplifier.
		Check range attenuator voltage line from range stepping switch to chopper.
Readout display will neither increase nor decrease.	Selector switch in STANDBY position	Turn selector switch to ON position.
	Time delay relay tube in power supply not functioning	Replace time delay tube in power supply.
	No "up" or "down" pulses available at stepping switch coils	Repair pulse lines from amplifier to power supply or from power supply to stepping switch assembly.
	Defective thyratrons on amplifier board	Replace 5696 tube and 2D21 thyratrons.
	No error signal	Trace error signal and chopper thru amplifier. Correct reason for loss of signal.
		Replace chopper.
		Establish unknown input signal or feedback voltage at chopper.
	Amplifier saturated with noise	Observe effective shielding and grounding procedures.
		Replace amplifier tubes.
When input signal polarity is reversed, numerical reading differs by more than one digit.	See listings under "Unstable readout display": input ripple, stray noise, faulty 5751 or 5696 tubes, stepping switch wiper tension low, reference voltage faults, noisy resistor, faulty ground circuits in instruments.	See associated remedies under "Unstable readout display."
		Consult Section 5-1B, "Hum Control"
	Input signal DC amplitude actually changes when leads to instrument are reversed.	If differing readings are construed as "trouble," and not "desired data," then signal source may be at fault.
	Amplifier gain low	Readjust gain control.
Printer does not print.	Faulty relay.	Replace relay.
	Relay not being actuated.	Check pulse circuits to relay.

TROUBLESHOOTING CHART (continued)

SYMPTOM	PROBABLE CAUSE	REMEDY
Failure of relay to operate in auto position.	No pulses to diodes CR-13 and CR-14, Unit 1.	Check for pulses from stepping switch pulse lines.
	Diodes CR-13 and CR-14, Unit 1 open.	Replace diodes.
Failure of relay to operate in manual mode.	Faulty switch.	Replace switch.
	Open transistor.	Replace transistor.
Relay does not operate in any mode.	—28 volt supply not functioning.	Replace components as required in 28 volt supply.
Relay pulled in at all times in any position of panel switch.	Transistor shorted.	Replace transistor.
Printer prints before meter balances.	One of diodes CR-13 or CR-14, Unit 1, open.	Replace diode.

PARTS LIST

Section

Seven

This section lists the electrical parts used in the Industrial Series Instruments. Hardware items such as brackets, grommets, nuts and bolts have been deleted. All of the instruments discussed in this manual use these parts, but not all of the parts may be used in any one instrument. Consult the appropriate schematic for circuit reference number before selecting a part from the parts list for your parts order.
If any unlisted item is required, contact the factory or your regional sales and service office as listed in the *Appendix*.

NOTES:

See Page 39.

UNIT 1 — AMPLIFIER-POWER SUPPLY ASSEMBLY, 11375-027

CIRCUIT REFERENCE	DESCRIPTION	PART NO.	MFR. CODE	UNIT REQ.	REPLACEMENT PERCENTAGE	100 INSTR. SPARES REQ. FOR 1 YR.
UNIT 1	AMPLIFIER-POWER SUPPLY	11375-027	NLS	1	0	0
C-1, C-2, C-5, C-8, C-11, C-17	CAPACITOR: Fixed, 4 Section, Electrolytic (Com. Neg.) 20 μf, 250 V each section	5002-006	NLS	2	1	2
C-6, C-9, C-12, C-15	CAPACITOR: Fixed, 4 Section, Electrolytic, (Com. Pos.), 20 μf, 250 V each section	5002-005	NLS	1	1	1
C-3	CAPACITOR: Fixed, Mylar 1.0 μf, 100 V	Type 170	P	1	2	2
C-4	CAPACITOR: Fixed, Metalized Paper .05 μf, 400 V	GEM 415	V	1	5	5
C-7, C-10, C-18, C-19, C-20	CAPACITOR: Fixed, Ceramic, .01 μf, 1000 V	DD 103	I	5	2	10
C-13, C-14	CAPACITOR: Fixed, Mica, 200 μμf, 500 V	CM19B-201M	F	2	0	0
C-16	CAPACITOR: Fixed, .25 μf,	W4-22	M	1	0	0
C-21, C-22, C-30	CAPACITOR: Fixed, Ceramic, .05 μf, 600 V	DF503	I	2	0	0
C-23	CAPACITOR: Fixed, 2000 μf, 30 V	BSV53-20-30P8	U	1	1	1
C-24	CAPACITOR: Fixed, Electrolytic, 20 μf, 50 V	PTT94	A	1	1	1
C-25	CAPACITOR: Fixed, Electrolytic, 10 μf, 50 V	PTT92	A	1	1	1
C-26	CAPACITOR: Fixed, 1 μf, 600 V	D1690-20M	Z	1	1	1
C-27, C-28	CAPACITOR: Fixed, 2 μf, 200 V	ZD2P205	N	2	1	2
CR-1 THRU CR-10, CR-12 THRU CR-15	DIODE	1N2616	W	14	2	28
F-1, F-2	FUSE: 3AG, 1A "Slo Blo"	313001	T	2	4	8
J-1, J-2	CONNECTOR: Input	97-3102A-14S-7P-426	E	2	1	2
K-1	CHOPPER	CH457	DD	1	2	2
K-2	RELAY: Time Delay	115N010T	D	1	2	2

See Page 39.

CIRCUIT REFERENCE	DESCRIPTION	PART NO.	MFR. CODE	UNIT REQ.	REPLACE-MENT PER-CENTAGE	100 INSTR. SPARES REQ. FOR 1 YR.
J-3	CONNECTOR: Ext. Reference	97-3102A-14S-2P-426	E	1	1	1
K-3	RELAY: Print Control	KHP17D11-24	Y	1	2	2
Q-1	TRANSISTOR	2N651	W	1	2	2
R-1, R-2	RESISTOR: Fixed, Composition 3.3 Ohm, ±10%, 1 W		B	2	0	0
R-3	POTENTIOMETER: 250 Ohm	DH2717	J	1	2	2
R-4, R-5, R-6	RESISTOR: Fixed, Wirewound 2000 Ohm, ±10%, 5 W		X	3	0	0
R-7	RESISTOR: Fixed, Wirewound 12.5 K, .5%	PW1719	NLS	1	0	0
R-8	RESISTOR: Fixed, Composition 470 K, ±10%, ½ W		B	1	0	0
R-9	RESISTOR: Fixed, Composition 4.7 Ohm, ±10%, 1 W		B	1	0	0
R-10	POTENTIOMETER: 15 K, ±5%, 2 W	W10-P1-15K	G	1	1	1
R-11	POTENTIOMETER: 500 Ohm, ±5%, 2 W	W10-P1-500	G	1	1	1
R-12, R-15, R-17, R-22, R-26, R-27, R-39, R-52	RESISTOR: Fixed, Composition, 3300 Ohm, ±10%, ½ W		B	8	4	32
R-13, R-25, R-28	RESISTOR: Fixed, Composition, 120 K, ±10%, ½ W		B	3	1	3
R-14	RESISTOR: Fixed, Composition, 180 K, ±10%, ½ W		B	1	0	0
R-16, R-23	RESISTOR: Fixed, Composition, 4.7 Meg, ±10%, ½ W		B	2	0	0
R-18	POTENTIOMETER: 200 K	32972	J	1	2	2
R-19, R-20	RESISTOR: Fixed, Composition, 360 K, ±10%, ½ W		B	2	0	0
R-21	POTENTIOMETER: 25 K, 2 W	11350-029	NLS	1	1	1
R-24	RESISTOR: Fixed, Composition, 300 K, ±10%, ½ W		B	1	0	0

See Page 39.

CIRCUIT REFERENCE	DESCRIPTION	PART NO.	MFR. CODE	UNIT REQ.	REPLACEMENT PERCENTAGE	100 INSTR. SPARES REQ. FOR 1 YR.
R-29, R-30, R-33, R-34, R-36, R-37, R-41, R-42, R-43, R-44, R-57	RESISTOR: Fixed, Composition, 1.0 Meg, ±10%, ½ W		B	11	0	0
R-31	RESISTOR: Fixed, Composition, 15 K, ±10%, ½ W		B	1	0	0
R-32	RESISTOR: Fixed, Composition, 220 K, ±10%, ½ W		B	1	0	0
R-35	RESISTOR: Fixed, Composition, 27 K, ±5%, ½ W		B	1	1	1
R-38, R-47	RESISTOR: Fixed, Composition, 1200 Ohm, ±10%, ½ W		B	2	4	8
R-50	RESISTOR: Fixed, Composition, 470 Ohm, ±10%, ½ W		B	1	0	1
R-40	RESISTOR: Fixed, Composition, 47 K, ±10%, ½ W		B	1	0	0
R-45	RESISTOR: Fixed, Composition, 91 K, ±10%, ½ W		B	1	0	0
R-46	RESISTOR: Fixed, Composition, 51 K, ±10%, ½ W		B	1	0	0
R-48	RESISTOR: Fixed, Composition, 75 Ohm, 20 W		X	1	2	2
R-53	RESISTOR: Fixed, Composition, 120 Ohm, ±10%, ½ W			1	0	0
R-54	RESISTOR: Fixed, Composition, 8.2 K, ±10%, ½ W		B	1	0	0
R-55	RESISTOR: Fixed, Composition, 3900 Ohm, ±10%, ½ W		B	1	0	0
R-56	RESISTOR: Fixed, Composition, 100 Ohm, ±10%, ½ W		B	1	0	0
R-58, R-59	RESISTOR: Fixed, Composition, 6800 Ohm, ±10%, ½ W		B	2	0	0
R-60	RESISTOR: Fixed, Composition, 4700 Ohm, ±10%, ½ W		B	1	0	0
R-61	RESISTOR: Fixed, Composition, 1000 Ohm, ±10%, ½ W		B	1	0	0
S-1	SWITCH: Mode	11375-025	NLS	1	1	1
S-2	SWITCH: Power	11355-028	NLS	1	1	1
S-3	SWITCH: Slide, DPDT, 5A, 125 V	34-162	Q	1		

See Page 39.

CIRCUIT REFERENCE	DESCRIPTION	PART NO.	MFR. CODE	UNIT REQ.	REPLACE-MENT PER-CENTAGE	100 INSTR. SPARES REQ. FOR 1 YR.
T-1	TRANSFORMER: Power	11350-010	NLS	1	1	1
V-1	TUBE: Electron, 0B2		JJ	1	1	1
V-2, V-8, V-9	TUBE: Neon, 90-ST-2-S		CC	3	1	3
V-3	TUBE: Electron, 5751		JJ	1	5	5
V-4, V-5	TUBE: Electron, 12AX7		JJ	2	2	4
V-6, V-7	TUBE: Electron, 5696		JJ	2	2	4
V-10, V-11	TUBE: Electron, 2D21W		JJ	2	2	4
Miscellaneous, Unit 1:						
	CLAMP: Chopper	7T	EE	1	0	0
	STANDARD CELL	Min 1	O	1	1	1
	ZENER DIODE OVEN ASSEMBLY:	11271-213	NLS	1	1	1
CR-1	DIODE: Zener Reference Matched Pair	020359-A	S	1	5	5
OV-1	OVEN ASSEMBLY	11271-212	NLS	1	2	2
	CRYSTAL HOLDER ASSEMBLY	Type 70	H	1	0	0

UNIT 2 — STEPPING SWITCH BOARD ASSEMBLY, 11375-032

UNIT 2	STEPPING SWITCH BOARD ASS'Y	11375-032	NLS	1	0	0
J-1, J-3, J-4, J-7	CONNECTOR: 22 Pin	5009-22-8-5-3/32	L	4	0	0
J-2	CONNECTOR: Printer, 75 Pin with 54 Sockets	500C4-75X2-JR 97502	K	1 54	0 ½	0 27
J-5, J-6	CONNECTOR: 13 Pin	5009-13-8-5-3/32	L	2	0	0
R-1	RESISTOR: Fixed, Wirewound, 50 K, ±.1%	AW1224	NLS	1	0	0

See Page 39.

UNITS 3, 4, 5 — DECADE 1, 2, or 3 SWITCH ASSEMBLY, 11355-036

CIRCUIT REFERENCE	DESCRIPTION	PART NO.	MFR. CODE	UNIT REQ.	REPLACE-MENT PER-CENTAGE	100 INSTR. SPARES REQ. FOR 1 YR.
UNITS 3, 4 & 5	DECADE 1, 2, or 3 SWITCH ASS'Y	11355-036	NLS	3	0	0
K-1	Stepping Switch Assembly	11271-442	NLS	3	2	6
R-1	RESISTOR: Fixed, Wirewound 12.5 K, ±.03%	PW1719	NLS	3	0	0
R-2, R-3, R-4, R-5, R-6, R-7, R-8, R-9, R-10, R-11, R-12	RESISTOR: Fixed, Wirewound 5 K, ±.03%	PW1719	NLS	11	0	0

UNIT 6 — DECADE 4, SWITCH ASSEMBLY, 11355-041

UNIT 6	DECADE 4 SWITCH ASSEMBLY	11355-041	NLS	1	0	0
K-1	Stepping Switch Assembly	11271-443	NLS	1	1	1
R-1	RESISTOR: Fixed, Wirewound 12.5 K, ±.03%	PW1719	NLS	1	0	0
R-2 thru R-12	RESISTOR: Fixed, Wirewound 5 K, ±.03%	PW1719	NLS	11	0	0

See Page 39.

UNIT 7 — RANGE & POLARITY SWITCH ASSEMBLY, 11355-046

CIRCUIT REFERENCE	DESCRIPTION	PART NO.	MFR. CODE	UNIT REQ.	REPLACEMENT PERCENTAGE	100 INSTR. SPARES REQ. FOR 1 YR.
UNIT 7	RANGE & POLARITY SWITCH ASS'Y	11355-046	NLS	1	0	0
C-1	CAPACITOR: Fixed, .047 μf, 600 V	ZD6N473	N	1	2	2
C-2	CAPACITOR: Fixed, 1.0 μf, 1000 V	ZDP1816	N	1	2	2
K-1	Stepping Switch Assembly	11271-414	NLS	1	1	1
L-1	CHOKE	15459	FF	1	1	1
R-1	RESISTOR: Fixed, Wirewound 99.111 K, ±.05%	PW1719	NLS	1	0	0
R-2	POTENTIOMETER: Trimmer, 2 K, ±5%, 2 W	W10-P1-2K	G	1	2	2
R-3	RESISTOR: Fixed, Wirewound .89 Meg, ±.05%	PW1719	NLS	1	0	0
R-4	POTENTIOMETER: Trimmer 20 K, ±5%, 2 W	W10-P1-20K	G	1	2	2
R-5 thru R-13	RESISTOR: Fixed, Wirewound 1 Meg, ±.05%	PW1719	NLS	9	0	0
Miscellaneous — General:						
	KNOB: Dial, Skirted, Round, Matte Finish, Black	70-3-2G	AA	3	0	0
	VISOR:	2022-2	NLS	1	0	0
	CABLE ASSEMBLY: Input	15004-126	NLS	1	0	0
	NYES Clock Oil	55022	HH	0	0	0
	POWDERED MICA: "Motor Mica"		GG	0	0	0
	COLORLESS MINERAL OIL		KK	0	0	0
	READOUT ASSEMBLY	12219	NLS	1	0	0
	LAMP: 28 V	327	R	45	10	450
	SPRING: Readout Lamp	12145-001-3	NLS	60	5	300

CODE LETTER	MANUFACTURER	ADDRESS
A	AEROVOX CORPORATION	New Bedford, Mass.
B	ALLEN BRADLEY CO.	Milwaukee, Wisc.
C	ALLIED CONTROL COMPANY, INC.	New York 21, N.Y.
D	AMPERITE CO.	New York, N.Y.
E	AMPHENOL ELECTRONICS CORP.	Chicago 50, Ill.
F	ARCO ELECTRONICS, INC.	New York 13, N.Y.
G	ATOHM ELECTRONICS	Sun Valley, Calif.
H	BULOVA WATCH CO. Quartz Crystal Division	Woodside, N.Y.
I	CENTRALAB DIVISION Globe-Union Inc.	Milwaukee, Wisc.
J	CHICAGO TELEPHONE SUPPLY CO.	Elkhart, Ind.
K	CONSOLIDATED ELECTRODYNAMICS CORP.	Pasadena, Calif.
L	ELCO CORPORATION	Philadelphia 24, Pa.
M	ELECTRON PRODUCTS, INC.	Pasadena, Calif.
N	ELPAC, INC.	Fullerton, Calif.
O	EPPLEY LABORATORY, INC.	Newport, R.I.
P	JACKSON ELECTRONIC DEVELOPMENT CORPORATION	Seymour, Ind.
Q	G. C. ELECTRONIC CO.	Rockford, Ill.
R	GENERAL ELECTRIC COMPANY Miniature Lamp Dept.	Cleveland, Ohio
S	HOFFMAN ELECTRONICS CORP. Semi-Conductor Division	Evanston, Ill.
T	LITTELFUSE, INC.	Des Plaines, Ill.
U	MEC, INC., CAPACITOR DIVISION c/o Robison Co.	Torrance, Calif.
V	P. R. MALLORY & COMPANY, INC.	Indianapolis, Ind.
W	MOTOROLA SEMICONDUCTOR PRODUCTS, INC.	Phoenix, Ariz.
X	OHMITE MANUFACTURING COMPANY	Skokie, Ill.
Y	POTTER & BRUMFIELD	Princeton, Indiana
Z	PYRAMID ELECTRIC CO.	Darlington, S. C.
AA	RAYTHEON MANUFACTURING COMPANY Commercial Equipment Division	Waltham, Mass.
BB	SANGAMO ELECTRIC COMPANY	Springfield, Ill.
CC	SIGNALITE, INC.	Neptune, N. J.
DD	STEVENS-ARNOLD, INC.	South Boston, Mass.
EE	TIMES FACSIMILE CORPORATION	New York, N. Y.
FF	TRIAD TRANSFORMER CORPORATION	Venice, California
GG	SCIENTIFIC LUBRICANTS COMPANY	Chicago, Ill.
HH	SWARTCHILD & COMPANY	Chicago, Ill.
II	TEXAS INSTRUMENTS	Dallas, Texas
JJ	Any Brand Tube Meeting RETMA Specifications	
KK	Any Pharmacy	

APPENDIX

Section Eight

WARRANTY

Non-Linear Systems, Inc. warrants each instrument of its manufacture to be free from defects in material and workmanship. Our obligation under this warranty is limited to servicing or adjusting any instrument returned, prepaid, to the factory for that purpose within one year of delivery to the original purchaser.

This warranty does not cover lamp bulbs, semiconductors, tubes, choppers, fuses, or batteries. However, non-oil-bathed stepping switches are guaranteed for 90 days provided they have been lubricated in accordance with manufacturer's instructions.

Instruments returned to the factory are accepted only when prior authorization has been given by an authorized representative of Non-Linear Systems, Inc.

Non-Linear Systems, Inc. reserves the right to make changes in design at any time without incurring any obligation to install same on units previously purchased.

This warranty is expressed in lieu of all other obligations or liabilities on the part of Non-Linear Systems, Inc. and Non-Linear Systems, Inc. neither assumes nor authorizes any other person to assume for them any other liability in connection with the sales of Non-Linear Systems, Inc. instruments.

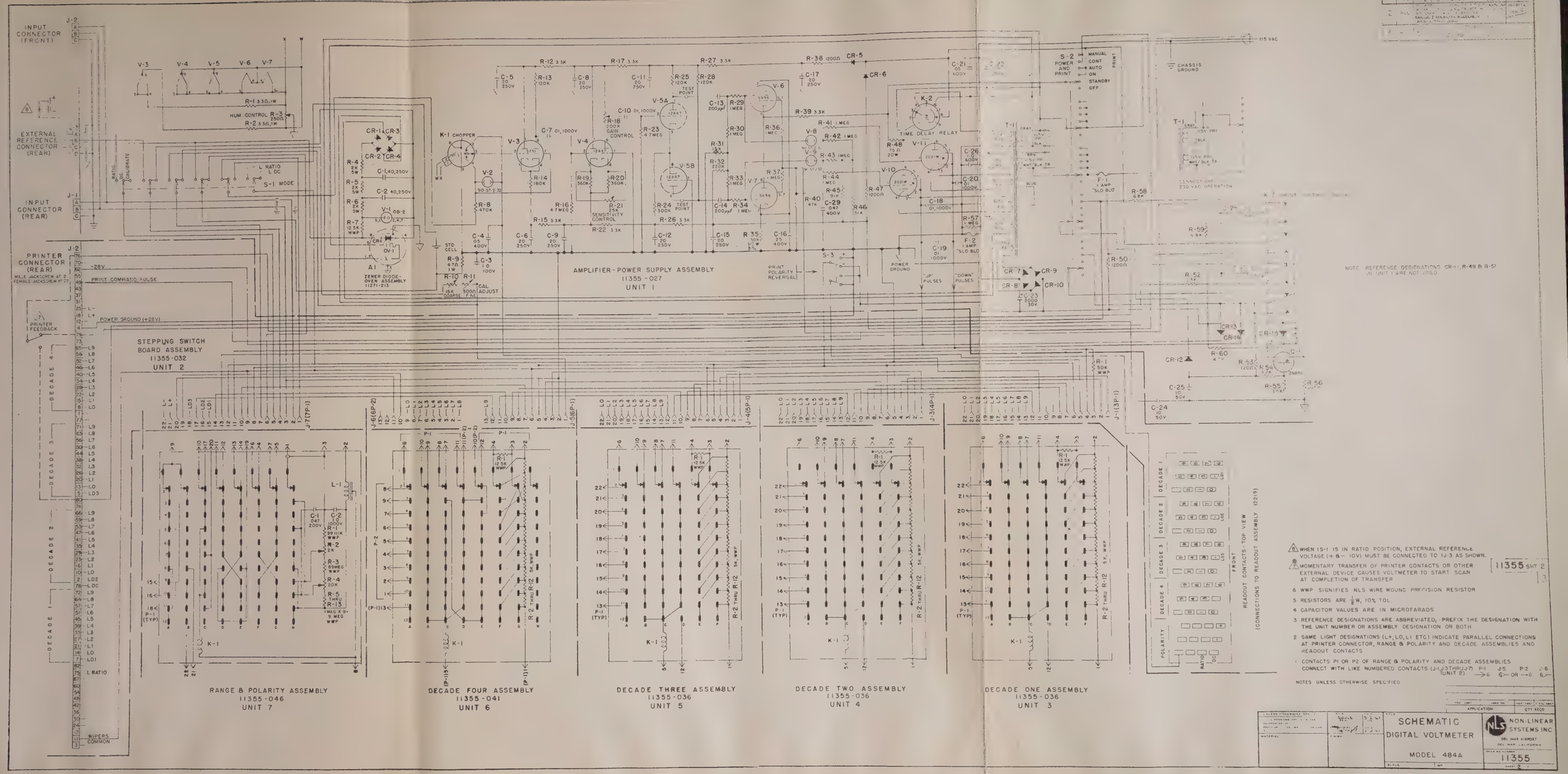
SHIPPING INSTRUCTIONS

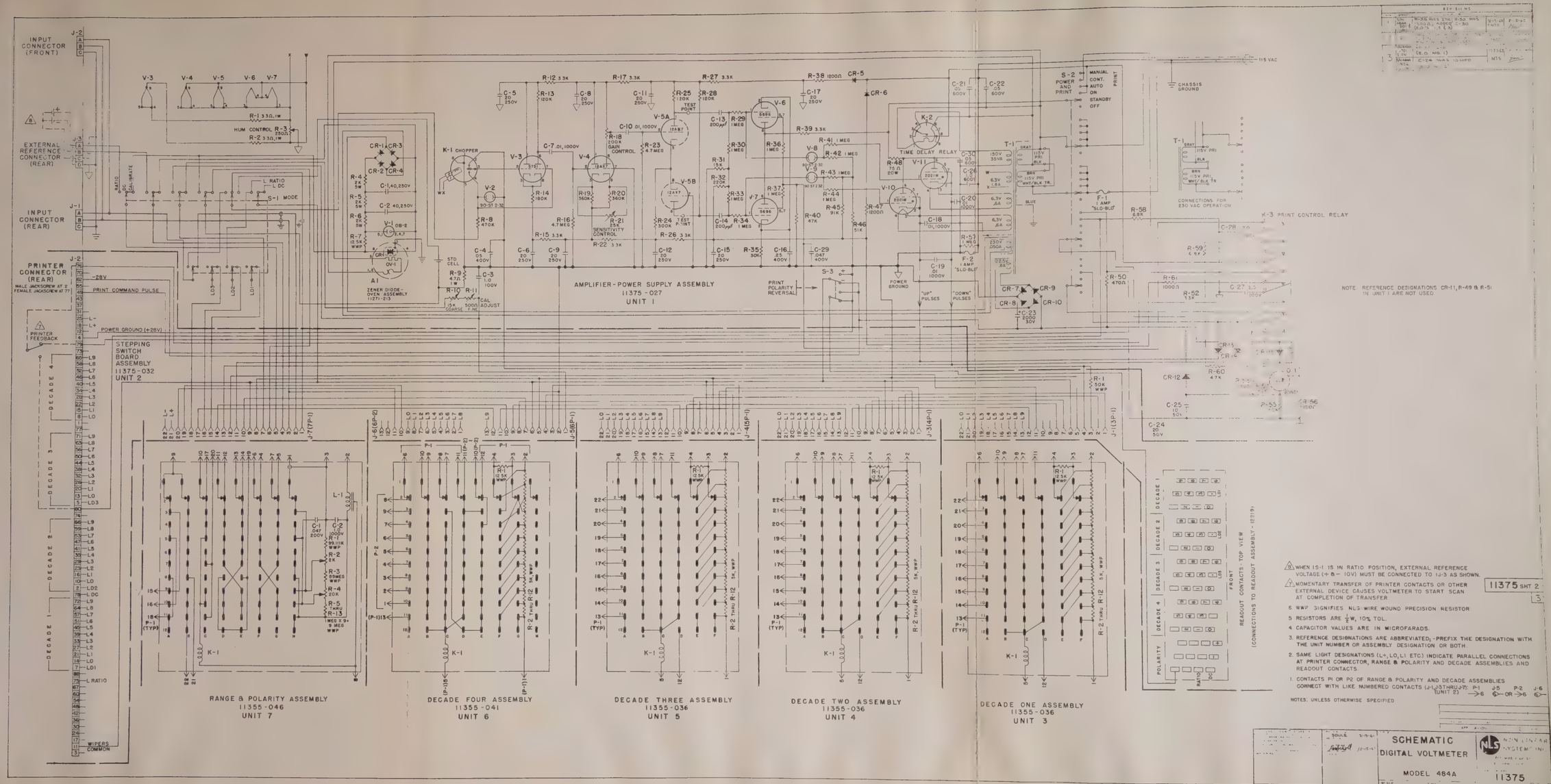
Depending upon location, the choice of carrier will vary. Never ship an instrument to us without having received shipping instructions. If requested an estimate of charges can be made before work begins.

Be certain to pack the instrument carefully; while an outer and inner box, separated by two or three inches of excelsior is desirable, the instrument can be placed into a single container provided it is so packed that it will not shift about. As with the double box method, use two or three inches of shock-absorbent packing materials. The instrument itself should be first wrapped in heavy paper so as to keep excelsior or other particles from entering the instrument's louvres.

CLAIM FOR DAMAGE IN SHIPMENT

The instrument should be tested as soon as it is received. If it does not operate or is damaged, a claim should be made with the carrier. The claim agent should receive a full report of damage, and this report sent to Non-Linear Systems, Inc. After receiving such a report we will advise you of the disposition of the instrument and arrange for its repair or replacement. Be certain to include model and serial number when corresponding.


INPUT CONNECTOR (FRONT)
EXTERNAL REFERENCE CONNECTOR (REAR)
INPUT CONNECTOR (REAR)
PRINTER CONNECTOR (REAR)
PRINTER FEEDBACK
AMPLIFIER-POWER SUPPLY ASSEMBLY 11355-027 UNIT 1
STEPPING SWITCH BOARD ASSEMBLY 11355-032 UNIT 2
RANGE & POLARITY ASSEMBLY 11355-046 UNIT 7
DECADE FOUR ASSEMBLY 11355-041 UNIT 6
DECADE THREE ASSEMBLY 11355-036 UNIT 5
DECADE TWO ASSEMBLY 11355-036 UNIT 4
DECADE ONE ASSEMBLY 11355-036 UNIT 3
TIME DELAY RELAY
CHASSIS GROUND
115 VAC
NOTE REFERENCE DESIGNATIONS CR-11, R-49 & R-51 IN UNIT 1 ARE NOT USED
WHEN I.S-1 IS IN RATIO POSITION, EXTERNAL REFERENCE VOLTAGE (+8— 10V) MUST BE CONNECTED TO I-J-3 AS SHOWN.
MOMENTARY TRANSFER OF PRINTER CONTACTS OR OTHER EXTERNAL DEVICE CAUSES VOLTMETER TO START SCAN AT COMPLETION OF TRANSFER
6 WWP SIGNIFIES NLS WIRE WOUND PRECISION RESISTOR
5 RESISTORS ARE 1/2W, 10% TOL.
4 CAPACITOR VALUES ARE IN MICROFARADS
3 REFERENCE DESIGNATIONS ARE ABBREVIATED, PREFIX THE DESIGNATION WITH THE UNIT NUMBER OR ASSEMBLY DESIGNATION OR BOTH
2 SAME LIGHT DESIGNATIONS (L+, LO, L1 ETC) INDICATE PARALLEL CONNECTIONS AT PRINTER CONNECTOR, RANGE & POLARITY AND DECADE ASSEMBLIES AND READOUT CONTACTS
1 CONTACTS P1 OR P2 OF RANGE & POLARITY AND DECADE ASSEMBLIES CONNECT WITH LIKE NUMBERED CONTACTS (J-1 J-3 THRU J-7) (UNIT 2) P-1 → J-5 P-2 → J-6
NOTES UNLESS OTHERWISE SPECIFIED
11355 SHT 2
READOUT CONTACTS - TOP VIEW (CONNECTIONS TO READOUT ASSEMBLY 12219)
SCHEMATIC
DIGITAL VOLTMETER
MODEL 484A
NON-LINEAR SYSTEMS INC
DEL MAR AIRPORT
DEL MAR, CALIFORNIA
11355



NOTE: REFERENCE DESIGNATIONS CR-11, R-49 & R-51 IN UNIT 1 ARE NOT USED.

⚠5 WHEN S-1 IS IN RATIO POSITION, EXTERNAL REFERENCE VOLTAGE (+ & − 10V) MUST BE CONNECTED TO J-3 AS SHOWN.

⚠4 MOMENTARY TRANSFER OF PRINTER CONTACTS OR OTHER EXTERNAL DEVICE CAUSES VOLTMETER TO START SCAN AT COMPLETION OF TRANSFER

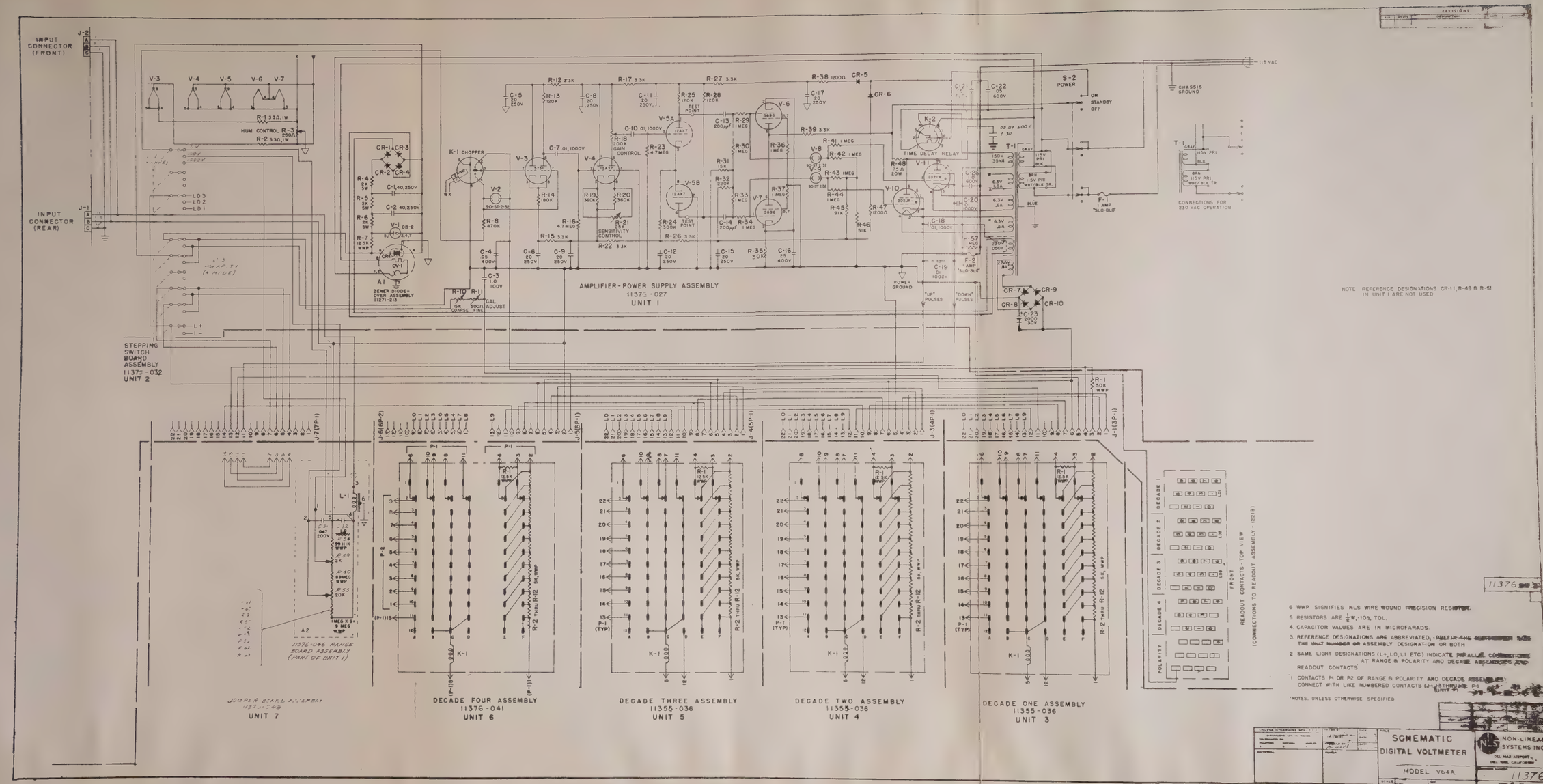
6. WWP SIGNIFIES NLS WIRE WOUND PRECISION RESISTOR
5. RESISTORS ARE ¼W, 10% TOL.
4. CAPACITOR VALUES ARE IN MICROFARADS.
3. REFERENCE DESIGNATIONS ARE ABBREVIATED, - PREFIX THE DESIGNATION WITH THE UNIT NUMBER OR ASSEMBLY DESIGNATION OR BOTH
2. SAME LIGHT DESIGNATIONS (L+, LO, L1 ETC) INDICATE PARALLEL CONNECTIONS AT PRINTER CONNECTOR, RANGE & POLARITY AND DECADE ASSEMBLIES AND READOUT CONTACTS
1. CONTACTS P1 OR P2 OF RANGE & POLARITY AND DECADE ASSEMBLIES CONNECT WITH LIKE NUMBERED CONTACTS (J-1 THRU J-7): P-1 (UNIT 2) →J-5 ←OR→J-6 ←, P-2 →J-6 ←

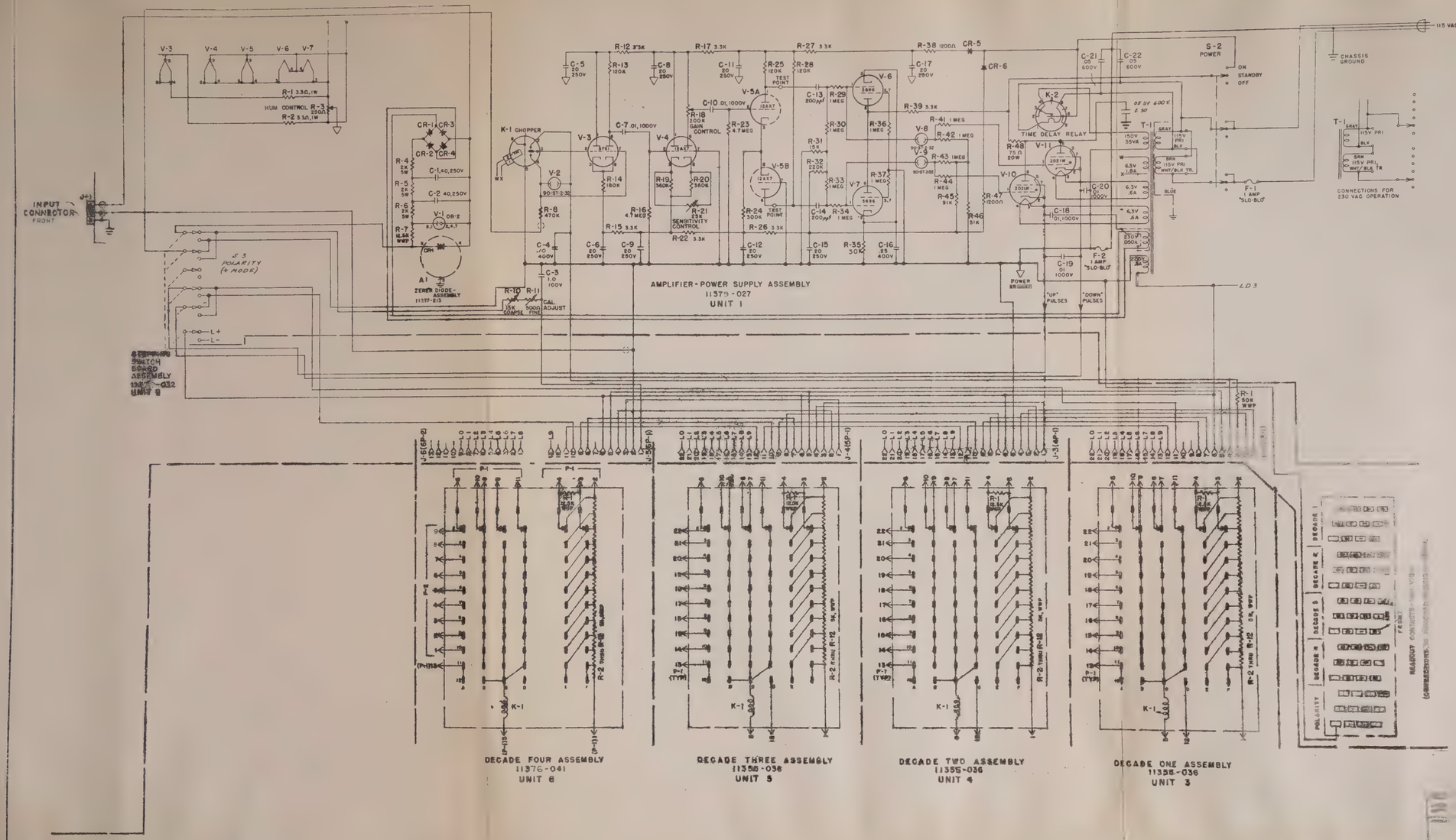
NOTES: UNLESS OTHERWISE SPECIFIED

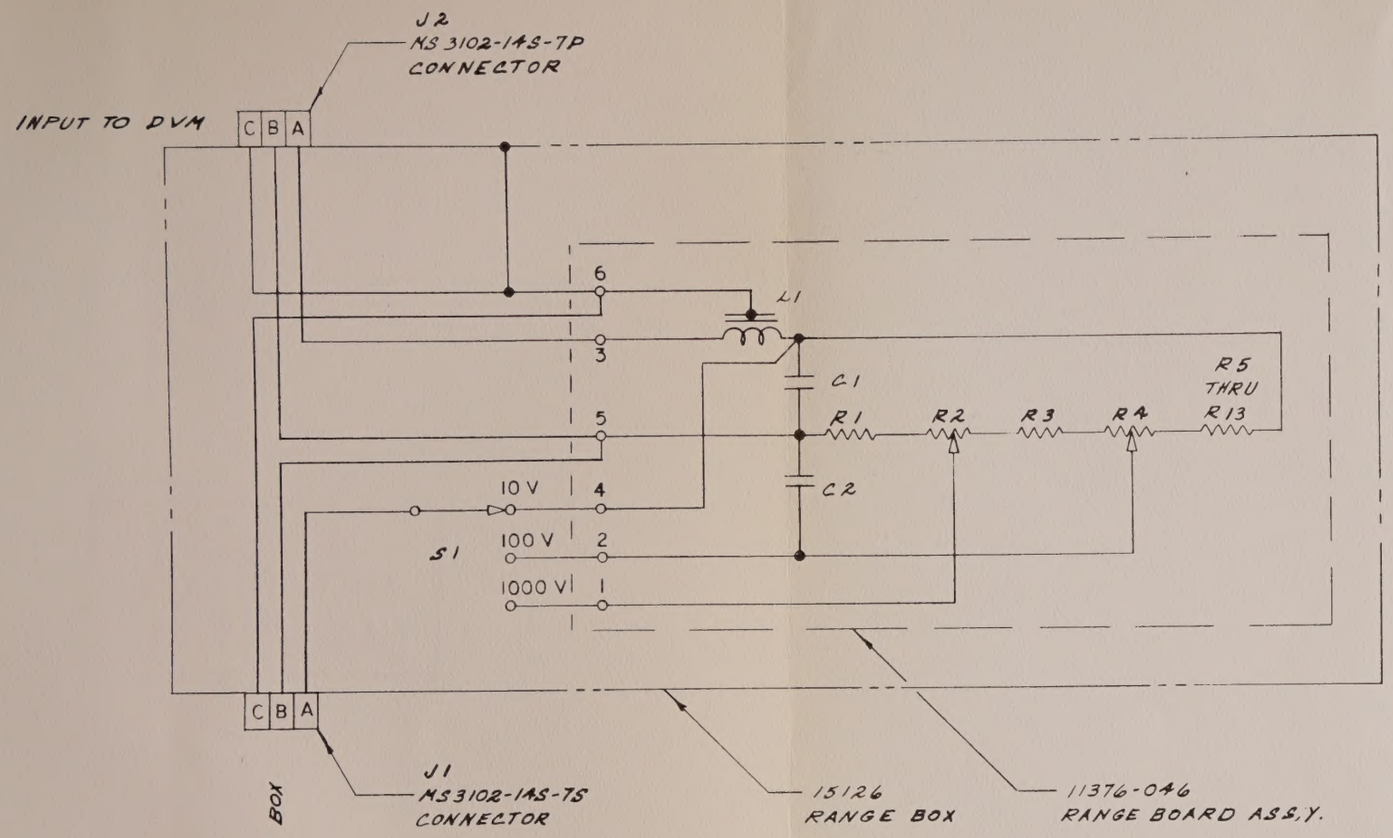
11375 SHT 2

REV	SYMS			
1	[illegible]	R-38 WAS 33K, R-50 WAS 1200Ω, ADDED C-30 (6-27-)	[illegible]	P. Ryan
2	[illegible]	[illegible] (8-0 NO.1)	[illegible]	[illegible]
3	[illegible]	C-24 WAS .1 MFD	MTS	[illegible]

SCHEMATIC
DIGITAL VOLTMETER
MODEL 484A
11375


INPUT CONNECTOR (FRONT)
INPUT CONNECTOR (REAR)
AMPLIFIER-POWER SUPPLY ASSEMBLY 11372-027 UNIT 1
STEPPING SWITCH BOARD ASSEMBLY 11372-032 UNIT 2
11376-046 RANGE BOARD ASSEMBLY (PART OF UNIT 1)
JUMPER BOARD ASSEMBLY 11372-048 UNIT 7
DECADE FOUR ASSEMBLY 11376-041 UNIT 6
DECADE THREE ASSEMBLY 11355-036 UNIT 5
DECADE TWO ASSEMBLY 11355-036 UNIT 4
DECADE ONE ASSEMBLY 11355-036 UNIT 3
TIME DELAY RELAY
CHASSIS GROUND
CONNECTIONS FOR 230 VAC OPERATION
READOUT CONTACTS - TOP VIEW
(CONNECTIONS TO READOUT ASSEMBLY - 12213)
NOTE: REFERENCE DESIGNATIONS CR-11, R-49 & R-51 IN UNIT 1 ARE NOT USED
6 WWP SIGNIFIES NLS WIRE WOUND PRECISION RESISTOR.
5 RESISTORS ARE ±1% TOL.
4 CAPACITOR VALUES ARE IN MICROFARADS
3 REFERENCE DESIGNATIONS ARE ABBREVIATED; PREFIX NUMBER SUFFIX TIME UNIT NUMBER OR ASSEMBLY DESIGNATION OR BOTH
2 SAME LIGHT DESIGNATIONS (L+, L0, L1 ETC) INDICATE PARALLEL CONNECTIONS AT RANGE & POLARITY AND DECADE ASSEMBLIES AND READOUT CONTACTS
1 CONTACTS P1 OR P2 OF RANGE & POLARITY AND DECADE ASSEMBLIES CONNECT WITH LIKE NUMBERED CONTACTS (L+ THRU L9) ON UNIT P1
*NOTES, UNLESS OTHERWISE SPECIFIED
SCHEMATIC
DIGITAL VOLTMETER
MODEL V64A
NON-LINEAR SYSTEMS INC.
DEL MAR AIRPORT
DEL MAR, CALIFORNIA
11376


INPUT CONNECTOR FRONT
S 3 POLARITY (4 MODE)
STEPPING SWITCH BOARD ASSEMBLY 11379-032 UNIT 9
AMPLIFIER - POWER SUPPLY ASSEMBLY 11379-027 UNIT 1
DECADE FOUR ASSEMBLY 11376-041 UNIT 8
DECADE THREE ASSEMBLY 11358-036 UNIT 5
DECADE TWO ASSEMBLY 11355-036 UNIT 4
DECADE ONE ASSEMBLY 11358-036 UNIT 3
TIME DELAY RELAY
CHASSIS GROUND
115 VAC
CONNECTIONS FOR 230 VAC OPERATION
6 WWP SIGNIFIES NLS WIRE WOUND PRECISION RESISTOR
5 RESISTORS ARE 1/2W, 10% TOL
4 CAPACITOR VALUES ARE IN MICROFARADS
3 REFERENCE DESIGNATIONS ARE ABBREVIATED, PREFIX THE DESIGNATION WITH THE UNIT NUMBER ON ASSEMBLY DESIGNATION ON BOTH
2 SAME LIGHT DESIGNATIONS (1-1, 2-1, ETC) INDICATE PARALLEL CONNECTIONS AT RANGE & POLARITY AND DECADE ASSEMBLIES AND READOUT CONTROLS
1 CONTACTS ON BACK OF RANGE & POLARITY AND DECADE ASSEMBLIES CONNECT WITH LIKE NUMBERED CONTACTS (J1 THROUGH P1 J5 P2 J6 (UNIT 2) P6 OR P6
NOTES UNLESS OTHERWISE SPECIFIED
SCHEMATIC
DIGITAL VOLTMETER
MODEL V64B
NON-LINEAR SYSTEMS INC
11379



15126

SHEET 2

ITEM	REQ'D	PART NUMBER	DESCRIPTION	MATERIAL OR MANUFACTURER
11	1	J2	MS3102-14S-7S	AMPHENOL
10	1	J1	MS3102-14S-7P	AMPHENOL
9	9	R5 THRU R13	1 MEG.	WWP NLS
8	1	R4	20 K	AT OHM
7	1	R3	.89 MEG.	WWP NLS
6	1	R2	2 K	AT OHM
5	1	R1	99.111K	WWP NLS
4	1	S1	11325-218	CENTRALAB & NLS
3	1	C2	.047 Uf	ELPAC
2	1	C1	1.0 Uf	ELPAC
1	1	L1	50 H	TRIAD

LIST OF MATERIALS

NEXT ASSY	USED ON	NEXT ASSY	FINAL ASSY

APPLICATION — QTY REQD

UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
TOLERANCES ON
FRACTION ± DECIMAL ± ANGLES ±

MATERIAL

FINISH

DRAWN BY	J.A.COMBS	DATE 3-1-62
CHECKED BY	R.WEINBERG	DATE 7-17-62
APPROVED BY	W Foley	DATE 7-17-62

TITLE
SCHEMATIC
DC ATTENUATOR,
V64B

SCALE — WT.

NON-LINEAR SYSTEMS INC.
DEL MAR AIRPORT
DEL MAR, CALIFORNIA

DRAWING NUMBER 15126

SHEET 2 OF

NOTES, UNLESS OTHER WISE SPECIFIED

A3-277
METROLOGY
LABORATORY

A3-277
METROLOGY
LABORATORY

non linear
systems, inc.

DEL MAR, CALIFORNIA

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